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Article

Seasonal variation of isoprene emissions from tropical roadside plant species and their possible role in deteoriating air quality

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Abstract

In the present study, two widely adapted common Indian plant species viz. *Dalbergia sissoo* and *Nerium oleander* were examined for normalized isoprene emission rate (NIER) using dynamic flow through bag enclosure technique. An attempt has also been made to evaluate suitability of these two selected plant species for city plantation programmes. *Dalbergia sp.* has got high isoprene emission (84.67 ± 3.87 µg/g/h) while *Nerium sp.* has minimum (0.001± 0.17 µg/g/h) during summer season as compared to monsoon season. Thus, *Nerium oleander* falls under low isoprene emitting category while *Dalbergia sissoo,* under high isoprene emitting category. The plants having low emitting isoprene rate due to non-functionalization of this light-dependent Isoprene-synthase (IspS). Hence, *Nerium oleander* should be encouraged for further city plantation at roadsides and *Dalbergia sissoo* should be done on low scale expecting reduction of other harmful pollutants in air.

Keywords isoprene; India; plant species; roadside; air quality.

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1 Introduction

Isoprene is emitted by plants to increase their thermo-tolerance (Sharkey and Singsaas, 1995, Singsaas et al., 1997). It is the single largest source of non-methane hydrocarbon for the atmosphere in many areas (Rasmussen, 1970; Guenther et al., 1995, Sharkey, 1996; Lerdau and Keller, 1997), comparable to methane in total amount entering the atmosphere globally (Brasseur and Chatfield, 1991). Isoprene reacts very quickly with hydroxyl radicals and ozone in the atmosphere. When sunlight and the nitrogen oxide (NOx) concentration are low, isoprene reactions in the atmosphere result in cleaner air (Trainer et al., 1987). However, in sunlight when NOx is present, isoprene reactions cause ozone formation (Chameides et al., 1988). Ozone-control strategies rely upon knowing whether the ozone formation is hydrocarbon limited or NOx limited.

Given the policy implications of biogenic hydrocarbon emissions, it is important to be able to accurately predict these emissions under a variety of environmental conditions. A better understanding of isoprene emission would allow better models for predicting ozone episodes, allowing mitigation measures such as programs encouraging reduced car travel on the day most likely to have high ozone concentrations.

It has long been known that isoprene emission is highly temperature and light dependent (Sanadze and Kursanov, 1966; Tingey et al., 1979; Monson et al., 1992). Isoprene emission increases up to 35°C to 40°C even when carbon assimilation is declining. This uncoupling of emission from photosynthesis contributed to the hypothesis that isoprene may protect plants against heat stress (Sharkey and Singsaas, 1995; Singsaas et al., 1997). The rate of isoprene emission declines above its optimum, but the optimum temperature is significantly affected by the protocol of isoprene emission measurement (Singsaas et al., 1999; Singsaas and Sharkey, 2000). If measurements are made quickly, the optimum is much higher than if the measurements are made slowly. This occurs because isoprene emission above 35°C is unstable, increasing when the temperature is first raised but then falling back after 10 to 20 min at the higher temperature. A mechanistic understanding of the regulation of isoprene emission with changes in temperature is important to accurately model isoprene output in future environments where global mean temperature is predicted to rise. In case of light, short-term (up to 20 min) effects of light intensity on isoprene emission rates, leaves that develop in full sun emit isoprene at a higher rate than leaves that develop in shade (Sharkey et al., 1991; Harley et al., 1994).

Isoprene emission is species specific, varying as much as four orders of magnitude depending upon the plant species (Benjamin et al., 1996). So, large scale planting of high isoprene emitting plant species is associated with potential air quality liability, particularly in polluted urban air sheds. In view of this, it is important to select low emitting plant species for plantation programmes. Till now, in our country, isoprene emission potential of plant species is not taken into consideration while selecting plant species for greenbelt development programme, probably due to limited availability of information on emission rates of plant species. In the present study, isoprene emission capacity at the bottom of the canopies of *Dalbergia sissoo* and *Nerium oleander* at different sites selected on the basis of land use pattern *viz.* Site RZ1: near to traffic intersection with dense vegetation, Site RZ2: away from traffic intersection with dense vegetation under floodplain area and Site RZ3: away from traffic intersection with dense vegetation under hilly ridge area during three different seasons (monsoon, winter and summer) in Delhi were measured. The plant species i.e. *Dalbergia sissoo* and *Nerium oleander* were selected for the study on the basis of their wide abundance (Table 1), local availability and representation of certain families and genera. In addition to that, *Dalbergia sissoo* has got highest calculated Air Pollution Tolerance Index (APTI) value (90.4) and comes under tolerant category while *Nerium oleander* has got lowest APTI value and comes under sensitive category among seven selected plant species as shown in Fig. 1 (Saxena et al., 2010). Moreover, other studies (Singh and Rao, 1983; Lui and Ding, 2008; Aarti et al., 2012; Radha priya et al., 2012) also reports similar results. Besides, Varshney et al. (2003) reported *D. sissoo* and *N. Oleander* to be the highest isoprene emitting and least isoprene emitting plant species, respectively. In this study, the objective was set-up to i) analyze and assess the normalized isoprene emission rate (NIER), especially at three selected sites in Delhi which are categorized on the basis of land use pattern during three different seasons (monsoon, winter and summer) in Delhi and ii) to estimate total isoprene emission (*D. sissoo* and *N. oleander*) rate at selected sites so as to depict how a highly emitting plant is responsible for increasing the concentration of isoprene pollution at the site and indirectly responsible for high production of tropospheric ozone.

Table 1 Diversity of selected plant species.

S.N.	Sites	*D. sissoo*	*N. oleander*
1.	RZ1	50 (approx.)	30 (approx.)
2.	RZ2	3500 (approx.)	50 (approx.)
3.	RZ3	5000 (approx.)	20 (approx.)

Source: DDA, DU; Fact Sheet, YBP and Fact Sheet, ABP.

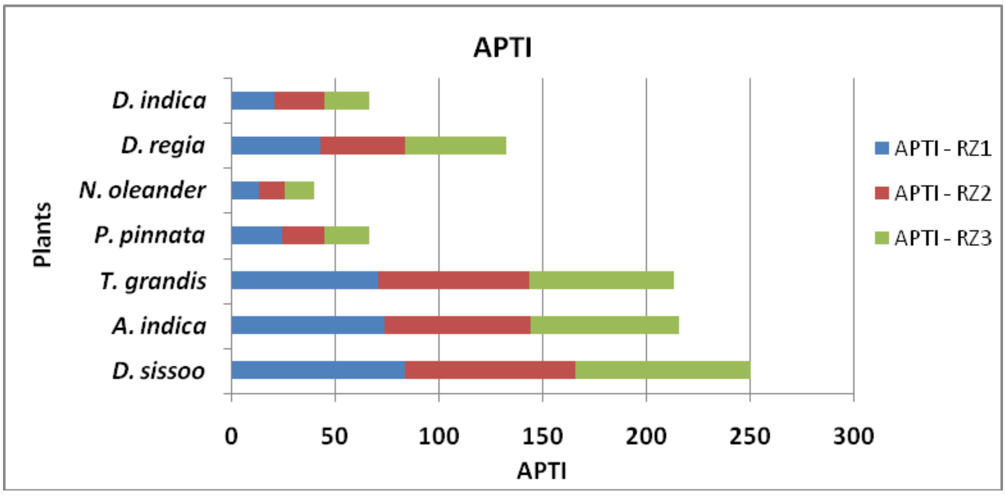

Fig. 1 APTI of plant species at selected sites in Delhi.

2 Material and Methods

2.1 Sites description

The capital city of India, Delhi, situated on the banks of Yamuna River, is one of its largest cities which lies at an altitude of between 700 and 1000 ft., with an area of approximately 1500 km^2. Delhi has a tropical steppe climate with continental air leading to relatively dry conditions and extremely hot summers. Monthly mean temperature ranges from 14.3°C in January (minimum 3°C) to 34.5°C in June (maximum 47°C) and the annual mean temperature is 25.3°C. There are three main seasons in Delhi, viz. monsoon, winter and summer. The mean annual total rainfall is 715 mm. Wind speeds are typically higher in summer and monsoon months than in winter. Based on a recent report by Goyal and Khaliq (2011), Delhi is among the 10 most polluted cities in the world. Population and transport are the main reasons behind the rising concentrations of air pollutants in Delhi. Creation of green belts has been identified as one of the most cost-effective air pollution abatement method. The flora in Delhi largely consists of some common trees like *Azadirachta indica*, *Ficus religiosa*, *Mangifera indica* and *Eucalyptus sp.* Besides these, other common ornamental plants and shrubs (*Dracaena deremensis* (Family:Dracaenaceae), *Lantana indica*, *Lantana camara*, *Bambusa indica*, *Tagetes erecta* (Family: Asteraceae), *Rosa indica* (Family: Rosaceae), *Dianthus caryophyllus* (Family:Caryophyllaceae), *Petunia hybrid* etc.) are planted in small adjacent gardens near different emitting zone, whether it is a residential, commercial, industrial or traffic intersection (Saxena and Ghosh, 2013).

Sampling sites were selected on the basis of land use pattern viz. near to traffic intersection with dense vegetation (Site RZ1: 500m from traffic zone), away from traffic intersection with dense vegetation under floodplain area (Site RZ2: 1.5km away from traffic zone) and away from traffic intersection with dense vegetation under hilly ridge area (Site RZ3: 2km away from traffic zone) during three different seasons (monsoon, winter and summer).

2.2 Plant material

Two commonly occurring plant species i.e. *Dalbergia sissoo* (Family: Fabaceae) and *Nerium oleander* (Family: Apocynaceae) were selected for the study on the basis of their wide abundance (Table 1), local availability and representation of certain families and genera. *D. sissoo* and *N. oleander* have the property to shed their leaves in Jan-Feb and then gain new leaves from March onwards. Summer season (Apr - June) is considered to be the best for their abundant growth.

2.3 Selection of seasons

These commonly occurring plant species were sampled at three selected sites during three different seasons annually *viz.* summer (Apr-June), monsoon (Aug-Sept), winter (Nov-Dec). Sampling was done for 8 hours from 10:00 – 17:00 hrs for each plant species for 3 days continuously at each site in every selected month.

During the winter season (Nov - Feb), sampling was done during November and December only since these plants shed leaves and are left with hardly any leaves after these months of winter.

2.4 Isoprene measurement

The composition of volatile emissions is usually quantified by the analysis of air samples collected in glass or plastic containers in which branches of living plants are placed (Zimmerman et al., 1978; Knoppel et al., 1981). This method is known as branch enclosure method (Zimmerman et al., 1978). The end of a branch of a tree was carefully introduced into a glass cylinder of 800 mm (diameter). The outer end was connected to a sorption tube (250 x. 6 mm) packed with 0.6-0.7 g of Chromosorb. The air passing through an inlet in the plug was drawn through the tube and the sorbent layer at a rate of 0.5 l min^{-1} with the help of Organic Vapor Sampler (OVS). The total sample volume was 4.78 l. The temperature was measured with a thermometer and light was measured with quantum sensor (Model No. SI: 121) located inside the cylinder. After the sampling had been finished, the leaves were separated and weighed. Desorption of the adsorbed isoprene was done using carbon disulfide (CS_2). CS_2 has the property to dissolve the gases properly which are adsorbed in chromosorb. The substances desorbed in the CS_2 were analyzed by capillary gas chromatography (Shimazdu, GC-2010), equipped with Supelcowax column. A flame ionization detector (FID) was used for analysis while quantification was done using the standards from Sigma Aldrich. The mass spectra were recorded at 70eV with accelerating voltage of 3.5 kV cathode current of 25 PA. The initial identification was carried out according to mass spectra and further identification was performed from the retention parameters of chromatographic peaks.

2.5 Measurement of environmental parameters

Temperature and Photosynthetic Active Radiation (PAR) was measured both outside and inside of experimental set-up (Table 2 and 3(a) & (b)). PAR was measured by Apogee Quantum Meter (Model no. MQ-200) µmol/m^2/s after every 1 hour. The sensor of the Quantum Meter was inserted inside the glass chamber and suitably oriented for measurement. Temperature readings were taken after every 1 hour in degree Celsius.

The temperature inside the enclosure chamber was found to be relatively higher (approx. 2°C). After the emission flux measurements were complete, the entire branch enclosed in the chamber was harvested and the leaves were dried in an oven at 70°C to a constant weight.

Table 2 Mean temperature and PAR at selected sites.

S.N	Sites	Avg. Temp.	Avg. PAR	N	SD
1	RZ1	28.87	453.09	21	3.80
2	RZ2	29.34	442.90	21	2.67
3	RZ3	30.11	421.57	21	3.02

Table 3(a) Mean isoprene emission rates (µg/g/h), temperature (°C) and PAR (µmol/m^2/s) of *Dalbergia sissoo* (Family: Fabaceae) inside experimental set-up.

S.N	Sites	NIER	SD	N	Avg. Temp.	Avg. PAR
1	RZ1	60.14	1.80	21	32.33	574.09
2	RZ2	51.65	0.77	21	36.73	586.90
3	RZ3	51.60	0.43	21	34.19	575.57

Table 3(b) Mean isoprene emission rates (µg/g/h), temperature (°C) and PAR (µmol/m^2/s) of *Nerium oleander* (Family: Apocynaceae) inside experimental set-up.

S.N	Sites	NIER	SD	N	Avg.Temp.	Avg. PAR
1	RZ1	0.02	0.01	21	33.37	578.75
2	RZ2	0.03	0.01	21	37.61	592.73
3	RZ3	0.02	0.01	21	35.30	581.11

2.6 Normalization of isoprene emission rate

Measured isoprene emission rates were normalized to PAR 1000 µmol/m^2/s and temperature 30°C, using the algorithm proposed by Guenther et al., 1993 and subsequently modified by Guenther (1997).

Isoprene emission rates were normalized as

$$I = MR/C_L\,C_T$$

I = normalized emission rate (µg/g dry leaf weight/h)

where MR: measured emission rate; C_L & C_T: light and temperature coefficient derived from experimental measurements on various plant species and are defined by

$$C_L = \alpha\, C_1 L/\,(1 + \alpha^2 + L)^{1/2}$$

where, L: PAR (µmol/m^2/s), C_1: empirical coefficient (1.067), and α: an empirical coefficient (0.0027)

$$C_T = \mathrm{Exp}\,\{C_{T1}\,(T\text{-}Ts)\,(R.TsT)^{-1}\}/0.961+\mathrm{Exp}\,\{C_{T2}\,(T\text{-}Tm)\,(R.Ts.T)^{-1}\}$$

where T: the leaf temperature in °K, R: gas constant (8.314 J/Kmol), Ts: normalising temperature in °K, Tm: an empirical coefficient (314K), C_{T1}: an empirical coefficient (95,000 J/mol), and C_{T2}: an empirical coefficient (230,000 J/mol).

2.7 Calculation of isoprene emission rate of selected plant species at particular sites (Westberg et al., 2000)

$$E_{ISO} = n \times Es_{(D.\ sissoo)} C_L C_T km^2{}_{(Site)} + n \times Es_{(N.\ oleander)} C_L C_T km^2{}_{(Site)}$$

where E_{ISO} = Total isoprene emission rate, n = number of plants in each species, Es = isoprene emission rate of particular plant species, C_L & C_T = respectively light and temperature coefficient, Km^2 (Site) = area of each site.

3 Results and Discussion

The isoprene emission rates were measured for two different plant species viz. *Dalbergia sissoo* and *Nerium oleander* at three different selected sites viz. RZ1 (near to traffic intersection with dense vegetation), RZ2 (away from traffic intersection with dense vegetation under floodplain area) and RZ3 (away from traffic intersection with dense vegetation under hilly ridge area). Mean isoprene emission rates of individual tree plant species, avg. temperature, PAR and number of emission samples for each species are given in Table 3 (a) & (b). The mean isoprene emission rates varied from 51.60 ± 0.43 µg/g/h – 60.14 ± 1.80 µg/g/h at selected sites in case of *D. sissoo* (Table 3 (a)) while in case of *N. oleander*, it varied from 0.02 ± 0.01 µg/g/h – 0.03 ± 0.01 µg/g/h (Table 3 (b)). Maximum isoprene emission rate was observed in case of *D. sissoo* as compared to *N. oleander* irrespective of sites. Moreover, Table 4 (a) and (b), showed significant variation of foliar mass during different seasons in both the plant species. Significant decrease in foliar mass was noticed in both the plant species during winter season as compared to summer and monsoon while non-significant variation was observed between summer and monsoon seasons. This is because during winter season, leaves were shed off in both the plant species, resulting in lower foliar mass estimation.

Table 4(a) Mean foliar mass (g dry.wt/branch) of *Dalbergia sissoo* (Family: Fabaceae) at selected sites during different seasons.

Seasons	**RZ1**	**RZ2**	**RZ3**
Summer	36.63 ± 2.00^a	40.4 ± 3.08^a	34.13 ± 1.50^a
Winter	20.25 ± 5.02^b	20 ± 7.21^b	20 ± 1.55^b
Monsoon	34.4 ± 2.12^a	37.7 ± 1.27^a	36.65 ± 0.63^a

Table 4(b) Mean foliar mass (g dry.wt/branch) of *Nerium oleander* (Family: Apocynaceae) at selected sites during different seasons.

Seasons	**RZ1**	**RZ2**	**RZ3**
Summer	41.6 ± 1.13^a	44.23 ± 0.58^a	44.57 ± 1.52^a
Winter	26.3 ± 3.39^b	27.35 ± 3.46^b	24.85 ± 2.90^b
Monsoon	43.45 ± 0.63^a	43 ± 2.82^a	41.9 ± 1.41^a

Note: In the above Tables 4.4 (a & b), each value represents mean of 6 replicates ± standard deviation. Data followed by different letters in a column are significantly different at P≤0.05. Data followed by same letters in a row are non-significant at P≤0.05.

Plant species screened for isoprene emission in the present study may be grouped into 2 categories proposed by Karlik and Winer (2001), namely i) BDL isoprene emitting (≤ 1 µg/g/h) ii) low emitting (1≤ to < 10 µg/g/h) iii) moderate emitting (10 ≤ to < 25 µg/g/h) and iv) high emitting (≥ 25 µg/g/h). Table 3 (a) & (b), shows that in the present study, *Nerium oleander* falls under BDL isoprene emitting category and *Dalbergia sissoo*, under high isoprene emitting category. Some progress has been made in explaining that "why some plants emit high or low isoprene". It has been assumed that the capacity for enzyme-catalysed isoprene emission has evolved independently within distinct lineages of plants, and may have been lost from some lineages (Loreto et al., 1998; Harley et al., 1999; Sharkey et al., 2005). For example, Family Fabaceae has groups with high taxonomic diversity with numerous isoprene-emitting genera and the trait is distributed among traditionally defined subfamilies (Monson et al., 2012) and this statement is in accordance with our observations described above in case of *D. sissoo* which comes under Family Fabaceae whereas Family Apocynaceae has less taxonomic diversity and the trait is not normally distributed like in our findings in case of *N. oleander*. In addition to that, isoprene is synthesized by the action of IspS (isoprene synthase) on DMADP (Silver and Fall, 1991) produced by the MEP pathway (Schwender et al., 1997). In plants which emit low emissions, it is more likely that non-functionalization of this light-dependent IspS occur which ultimately is responsible for an inability to generate adequate dimethylallyl diphosphate (DMADP) substrate causing mutations in the MEP pathway which tend to interfere with metabolic processes that are crucial to plant survival and ultimately emit less isoprene (Estevez et al. 2001; Fares et al., 2006; Rodriguez-Concepción, 2010). In addition to that, *D. sissoo* is a deciduous tree and trees are generally the biggest isoprene emitters. In the tropics, plant leaves can grow very large, and this creates a large boundary layer insulating the leaf from air temperature, allowing the leaf temperature to exceed air temperature by 10^oC and more. Also, in humid air, heat loss by latent heat of evaporation is reduced. The humid tropics are known to have many isoprene-emitting species (Sharkey and Yeh, 2001). Thus, there is a correspondence between the distribution of isoprene emission capacity among plant species and its presumed function in increasing tolerance of heat flecks suffered by leaves.

3.1 Seasonal variation in isoprene emission

Isoprene emission rates were measured during three seasons summer (Apr-Jun), monsoon (Aug-Sept) and winter months (Nov-Dec) annually at three different sites differentiated on the basis of near to traffic intersection with dense vegetation (RZ1), away from traffic intersection with dense vegetation (RZ2) and Hilly Ridge area (RZ3). For each species, three measurements were made in each selected month. Leaf age in case of each plant species was counted from onset of new leaves following the shedding of senescenced leaves. The highest isoprene emission rate was found in *Dalbergia sissoo* and minimum in *Nerium oleander* at all seasons and sites. Interestingly, there is no significant difference found among three months of summer season i.e. April (78.57 ± 3.41^a), May (82 ± 3.10^a) and June (82.67 ± 1.68^a) at RZ1, at RZ2 (66.17 ± 3.30^a, 71.77 ± 1.27^a, 75.4 ± 1.27^a) and RZ3 (69.93 ± 4.01^a, 75.9 ± 2.30^a, 78.43 ± 1.94^a) in case of *D. sissoo* (Table 5 (a)). Similarly, no significant difference was observed in case of *N. oleander* at all the sites and in all the months i.e. in April at RZ1 it was 0.04 ± 0.03^a, in May 0.04 ± 0.01^a and in June 0.04 ± 0.03^a during summer season (Table 5 (b) & Fig. 2).

During winter season, significant change was observed at all sites viz. RZ1, RZ2 and RZ3 in case of *D. sissoo*. At RZ1, high concentrations of isoprene were found in November (70.07 ± 2.41^a) as compared to December (65.17 ± 2.02^a) and similar result was found at RZ2, in November (52.17 ± 1.58^a) and December

(44.63 ± 4.30[a]) and at RZ3 in November it was 55.83 ± 3.59[a] and in December, 46.83 ± 3.52[a] (Table 6 (a)). In case of *N. oleander*, no significant change was observed at all sites during two months, Nov & Dec respectively viz. RZ1 (0.03 ± 0.02[a], 0.01 ± 0.00[a]), RZ2 (0.03 ± 0.02[a], 0.03 ± 0.01[a]) and RZ3 (0.02 ± 0.01[a], 0.03 ± 0.02[a]) (Table 4). In addition to that, *D. sissoo* and *N. oleander* showed significant difference in isoprene concentrations during winter season (Table 6 (b) & Fig. 3).

Table 5 (a) Variation in isoprene emission rates in *Dalbergia sissoo* during summer season

Sites	**Apr**	**May**	**Jun**
RZ1	78.57 ± 3.41[a]	82 ± 3.10 [a]	82.67 ± 1.68[a]
RZ2	66.17 ± 3.30[a]	71.77 ± 1.27[a]	75.4 ± 1.27[a]
RZ3	69.93 ± 4.01[a]	75.9 ± 2.30[a]	78.43 ± 1.94[a]

T**able 5(b)** Variation in isoprene emission rates in *Nerium oleander* during summer season

Sites	**Apr**	**May**	**Jun**
RZ1	0.04 ± 0.03[a]	0.04 ± 0.01[a]	0.04 ± 0.03[a]
RZ2	0.04 ± 0.02[a]	0.04 ± 0.02[a]	0.05 ± 0.02[a]
RZ3	0.02 ± 0.01[a]	0.03 ± 0.01[a]	0.03 ± 0.02[a]

Table 6 (a) Variation in isoprene emission rates in *Dalbergia sissoo* during winter season

Sites	**Nov**	**Dec**
RZ1	70.07 ± 2.41[a]	65.17 ± 2.02[a]
RZ2	52.17 ± 1.58[a]	44.63 ± 4.30[a]
RZ3	55.83 ± 3.59[a]	46.83 ± 3.52[a]

Table 6 (b) Variation in isoprene emission rates in *Nerium oleander* during winter season

Sites	**Nov**	**Dec**
RZ1	0.03 ± 0.02[a]	0.01 ± 0.00[a]
RZ2	0.03 ± 0.02[a]	0.03 ± 0.01[a]
RZ3	0.02 ± 0.01[a]	0.03 ± 0.02[a]

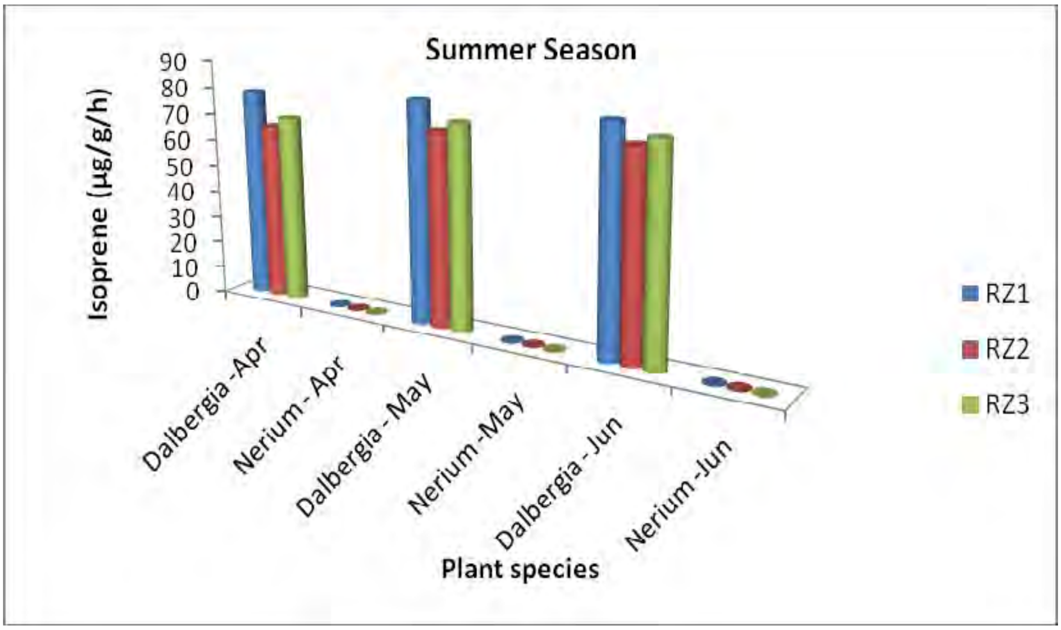

Fig. 2 Variation in isoprene emission rate in *Dalbergia* and *Nerium sp.* during summer season.

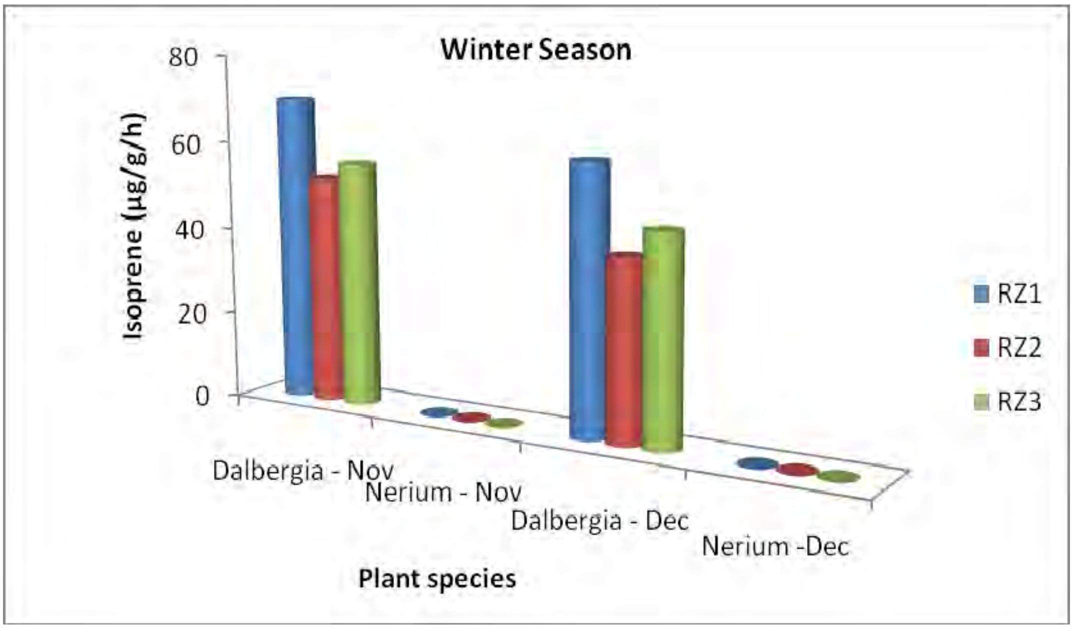

Fig. 3 Variation in isoprene emission rate in *Dalbergia* and *Nerium sp.* during winter season.

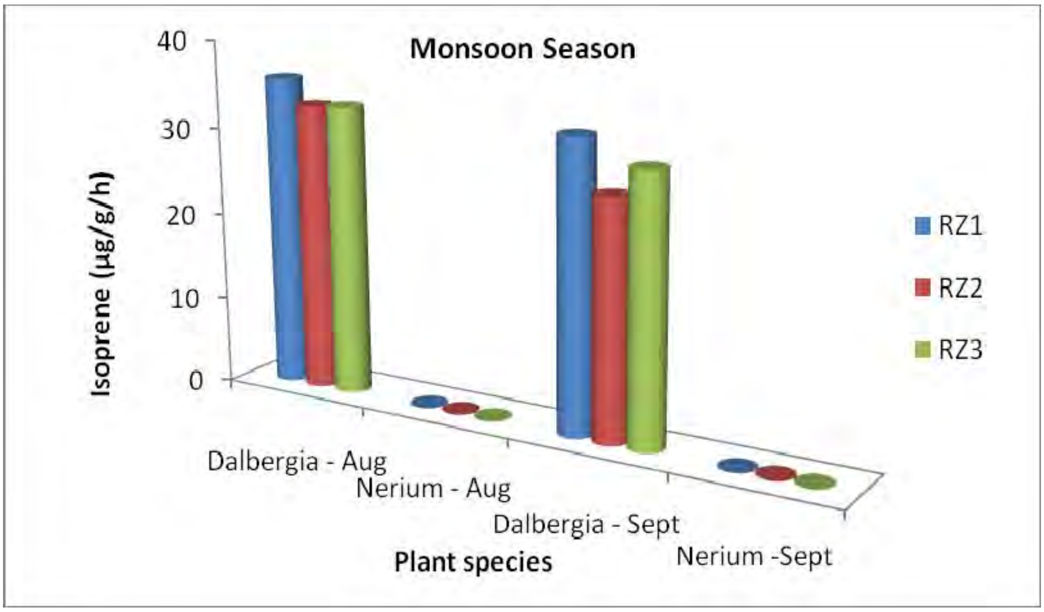

Fig. 4 Variation in isoprene emission rate in *Dalbergia* and *Nerium sp.* during monsoon season.

Table 7 (a) Variation in isoprene emission rates in *Dalbergia sissoo* during monsoon season.

Sites	**Aug**	**Sept**
RZ1	35.6 ± 2.69^a	32.9 ± 2.10^a
RZ2	32.87 ± 4.00^a	27.03 ± 2.70^a
RZ3	33.1 ± 3.10^a	30.33 ± 2.93^a

Table 7 (b) Variation in isoprene emission rates in *Nerium oleander* during monsoon season.

Sites	**Aug**	**Sept**
RZ1	0.01 ± 0.00^a	0.01 ± 0.01^a
RZ2	0.02 ± 0.01^a	0.02 ± 0.01^a
RZ3	0.01 ± 0.00^a	0.01 ± 0.01^a

Note: In the above tables 4.5 -4.7 (a & b), each value represents mean of 3 replicates ± standard deviation. Data followed by different letters in a row are significantly different at $P \leq 0.05$. Data followed by same letters in a row are non-significant at $P \leq 0.05$).

During monsoon season, no significant change was observed in Aug & Sept at RZ1(35.6 ± 2.69^a, 32.9 ± 2.10^a), RZ2 (32.87 ± 4.00^a, 27.03 ± 2.70^a) and RZ3 (33.1 ± 3.10^a, 30.33 ± 2.93^a) in case of *D. sissoo* (Table 7 (a)). In case of *N. oleander*, also no significant change was observed at all sites viz. RZ1 (0.01 ± 0.00^a, 0.01 ± 0.01^a), RZ2 (0.02 ± 0.01^a, 0.02 ± 0.01^a) and RZ3 (0.01 ± 0.00^a, 0.01 ± 0.01^a) (Table 7 (b) & Fig. 4).

Moreover, as per seasonal variation, highest isoprene emission rate was found during summer season followed by winter and then monsoon (Figs 2 – 4). The possible reason for such seasonal variation could be a combination of following factors viz. leaf age and temperature and solar radiation. Several studies have shown that leaf age strongly affects VOCs emission (Monson et al., 2007; Steinbrecher et al., 1997; Xiaoshan et al., 2000). Isoprene emission gradually increased till leaves attained maturity and subsequently declined in older and senescenced leaves. Isoprene emission was found to increase with leaf age till maturity (50 to 200 days) and then start decline and becomes minimum in senscenced leaves (Guenther et al., 1993; Monson et al., 1994). Leaf senescence or leaf shedding was responsible for negligible / below detectable limit of isoprene emission. Temperature and solar radiation strongly influence isoprene emission (Bruggemann and Schnitzler, 2002; Centritto et al., 2004; Copolovici et al., 2005). Monson et al. (2012) have reported suppression of isoprene emission in winter due to reduction in isoprene synthase activity.

3.2 Calculation of isoprene emission rate of selected plant species at particular sites

$$E_{ISO} = n \text{ x } Es_{(D.\ sissoo)}C_LC_T km^2{}_{(Site)} + n \text{ x } Es_{(N.\ oleander)}C_LC_T km^2{}_{(Site)}$$

The estimation of total isoprene emission rate per area/per site can be calculated as per the above formula given by Westberg et al., 2000 by using the data from Table 1. E_{ISO} of three different sites were found to be 434.87 μg/g/h, 1213.76 μg/g/h and 706.54 μg/g/h at RZ1, RZ2 and RZ3 respectively.

From the above data, it is observed that the total isoprene emission rate was highest at RZ2 followed by RZ3 and then RZ1. It clearly points out that RZ2 has high *D. sissoo* population as compared to RZ1 & RZ3. Therefore, total isoprene emission rate per area in terms of this species was quite high and the isoprene concentration decreases as the number of *D. sissoo* plants decreases at selected sites (Table 1).

4 Conclusion

The present study concludes that *Dalbergia sissoo* comes under high isoprene emission category while *Nerium oleander* comes under BDL isoprene emission category. In addition to that, Site RZ2 (away from traffic intersection with dense vegetation under floodplain area) has got high isoprene emission rates as compared to Site RZ1 (near to traffic intersection with dense vegetation) and RZ3 (away from traffic intersection with dense vegetation under hilly ridge area) which clearly depicts that the area where the population of tree species are of older category, they emit high isoprene.

During summer season, high isoprene emission rates were found followed by winter and monsoon. Moreover, the significant feature of this study is the estimation of total isoprene emission rate at selected sites which shows that higher the number of high isoprene emitting plant species, the higher the isoprene pollution in that area which is ultimately responsible for high production of tropospheric ozone. So, in other words, areas where *D. sissoo* plants are more, there are high chances of high ozone concentrations for which isoprene is responsible.

For any greenbelt development manager, it is very important to select the type of plant species to be planted. The present small study reflects that *Nerium oleander* should be planted at outskirts of selected areas and planting of *Dalbergia sissoo* should be done on low scale so that the air remains clean and indirect production of tropospheric ozone, aerosol production is minimized.

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