Impact of particulate pollution on photosynthesis, transpiration and plant water potential of teak (*Tectona grandis* L.)

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The study on teak *Tectona grandis* L. under particulate pollution stress caused by deposition of cement dust revealed that various physiological functions were hampered due to these pollutants. The dust accumulation was highest during summer (0.299 mg/sq. cm) in the polluted plot in comparison to control plot (0.037 mg/sq. cm). The effects of particulate pollution on *T. grandis* also varied with season, with a general trend of particulate pollutants having maximum effect on vegetation during summer and least during monsoon. The rate of photosynthesis was halved due to particulate pollutant deposition. Particulate pollution decreased the water potential of *T. grandis* during summer. The rate of transpiration in particulate pollution-affected trees was highly erratic, being the highest during monsoon and least during summer in comparison to those not exposed to pollution. All these induced morphological changes such as reduced height, girth, etc. and also reduced the effective growing days by shedding leaves in the trees exposed to particulate pollution. Leaf area index, which is an indicator of plant productivity, was almost half in pollution-affected trees than control trees. *T. grandis* can serve as an effective barrier in controlling the spread of pollutants. However, it is ineffective during summer, due the deciduous nature.

Keywords: Leaf area measurements, particulate pollution, photosynthesis, teak, transpiration.

AIR pollution is a broad term which can be defined as the presence of a substance which has harmful or poisonous effects in the air. Air-borne particulates are a complex mixture of organic and inorganic substances of varying size and possess the capacity to enter a plant through numerous ways. The most obvious damage of air-borne particles occurs in the leaves. Chlorosis, necrosis and epinasty are some of the major damages caused by air pollutants to plants[1].

Cement dust, largely made of kiln-dust is considered to be one of the major sources of air pollution. Cement dust can cause injuries to leaves, damage the stomata, closure of stomata, premature senescence, decrease the photosynthetic activity, disturb membrane permeability and reduce the growth in sensitive plant species[2,3]. The pleiotropic effects of air pollution include increased sensitivity to pest attack and modification of a plant's response to drought[4].

The present study focuses on the effect of particulate pollution on photosynthesis, transpiration and plant water potential of teak, *Tectona grandis* L., a common high-value commercial timber tree of the humid tropics.

The study was conducted at Walayar, Kerala, India (10°51′N 76°50′E). The study site has a government-operated cement factory. This area has been largely affected by particulate pollution, chiefly released from the cement factory. Control plot was selected at Vattapara (10°49′N 76°48′E), located about 5 km southwest of the polluted plots, which was used as a reference for understanding the degree to which the trees are affected by the particulate pollution and the tolerance levels of teak to dust pollution (Figure 1). The plantation near the cement factory was established in 1982, while the plantation at Vattapara (control plot) was established in 1981. Observations were made of 20 randomly selected trees for both the study sites.

The dust load on the leaf surface was measured following the methodology described by Prusty *et al.*[5]. The leaves at a height of 2 m from the ground were marked and cleaned using a brush. They were then left for 24 h to allow dust to accumulate on their surface. After 24 h, the surface of all the marked leaves was cleaned using a fine brush and the dust was collected in pre-weighed tracing paper. The leaves collected for dust accumulation measurement were measured for area after cleaning using a leaf area meter (LI-3000, LICOR, USA). The accumulated dust was calculated as

$$W = (W_2 - W_1)/n,$$

where W_1 is the initial weight of the petri dish without dust, W_2 the final weight of the petri dish with dust and n is the total area of the leaf (sq. cm).

The observations were taken during December–June, February–March and June–July representing winter, summer and monsoon season respectively. The rate of dust accumulation was calculated for a period (season) as the average of dust accumulated during a given season and that of the previous season and expressed as the rate of accumulation/month using the formula

$$\text{Rate of dust accumulation} = [\{(\mathrm{DA}_1 + \mathrm{DA}_2)/2\} \times (t_2 - t_1)]/\text{month},$$

where DA_1 is the dust accumulated at time (t_1) and DA_2 is the dust accumulated at time (t_2).

Leaf area measurements were done using Canopy Analyser (LAI 2000, LICOR, USA) during morning hours between 7.00 and 8.30 am. Leaf area duration (LAD) was calculated from the leaf area index (LAI)

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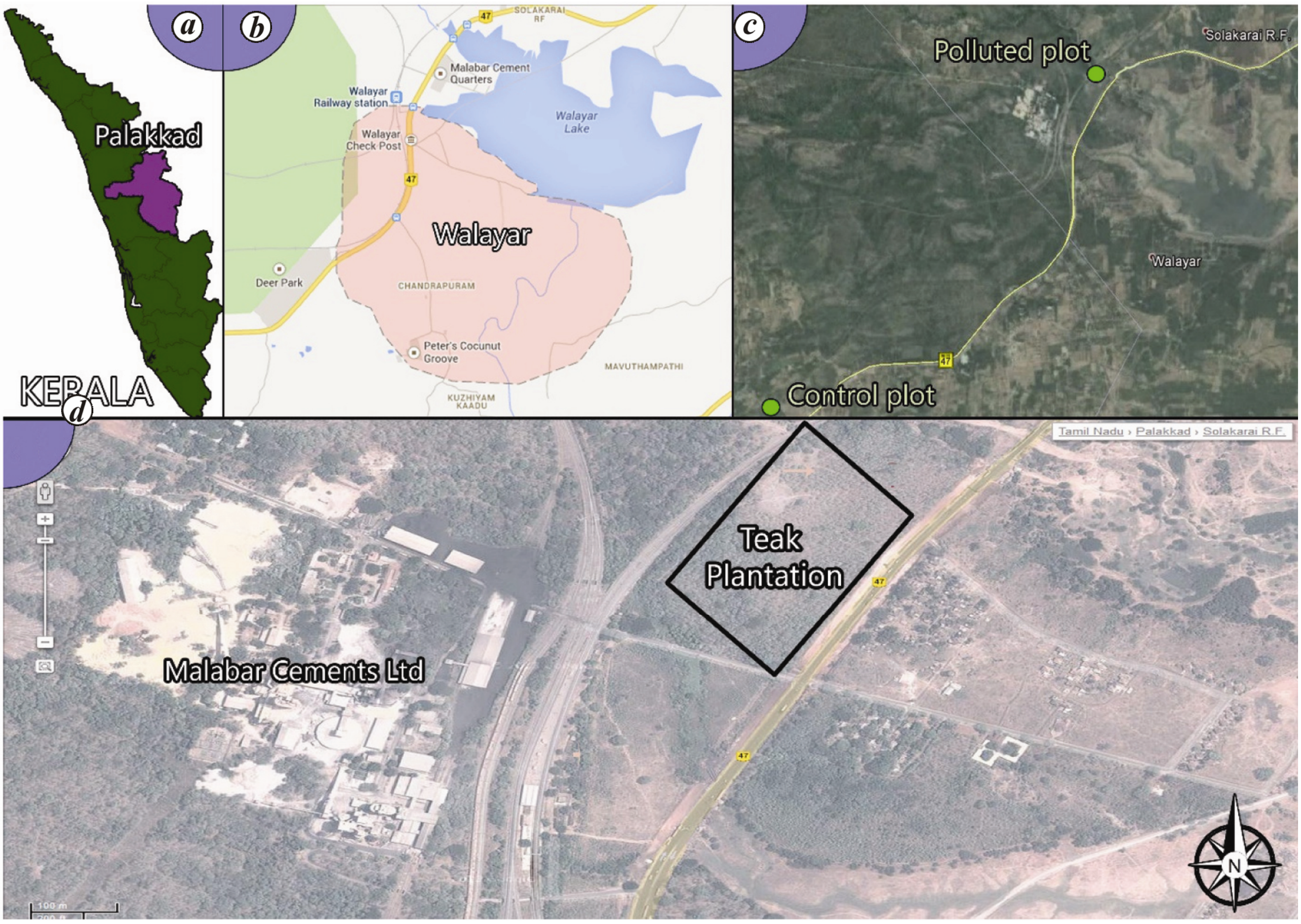

Figure 1. Location maps of the study area: ***a***, Map of Kerala; ***b***, Map of Walayar; ***c***, Location of polluted and control plots; ***d***, Location of polluted plot near Malabar Cements Ltd.

measurements for the intervals between winter (December), summer (March) and monsoon (June) seasons, as the average of LAI of a earlier and later season.

$$\mathrm{LAD} = [(\mathrm{LAI}_1 + \mathrm{LAI}_2)/2] \times (t_2 - t_1),$$

where LAI_1 is the leaf area index at time (t_1) and LAI_2 is the leaf area index at time (t_2).

The pre-dawn water potential of *T. grandis* leaves was measured with the aid of plant water status console (Soil Moisture Equipment Corporation, USA). The readings were taken in the field, as soon as the leaves were collected in order to avoid errors due to loss of water through the cut ends. The photosynthesis and transpiration of the trees were recorded using portable photosynthesis system between 8 and 9 am (LI-6400, LICOR, USA).

The height of the trees was measured using Haga's altimeter and the girth at breast height was measured using a measuring tape.

The leaves of *T. grandis* were under severe dust load in the polluted area (0.1721 mg/sq. cm) in comparison to the control plot (0.0246 mg/sq. cm; Table 1). The dust deposition was higher during winter and summer than during rainy season. The dust load was found to be highest during summer, followed by winter and least during monsoon (Table 1). The reason for high dust load during summer is due to the prolonged exposure without much precipitation to wash off the dust and reduced leaf area of *T. grandis* during this season (Table 1). The reduced leaf area during summer exposes individual leaves to maximum deposition, since there are less number of leaves to intercept and share the dust load. The dust load was significantly low during monsoon season in both plots, since the dust attached to the leaf surface was continuously removed by rainfall. The leaf area was higher during monsoon season in comparison to both winter and summer seasons.

The rate of dust accumulation was studied between winter and summer (December–March) and between summer and monsoon (March–June). The rate of deposition was higher during the December–March period.

It was observed that leaf shedding during winter occurred earlier in trees in the polluted area in comparison

Table 1. Various parameters studied on *Tectona grandis* in the polluted and control plots

Parameters	Plot	December–June (winter)	February–March (summer)	June–July (monsoon)	Mean
Dust accumulation (mg/sq. cm)	Polluted	0.205	0.299	0.012	0.172*
	Control	0.034	0.037	0.003	0.0245*
	Mean	0.120^{b}	0.168^{c}	0.007^{a}	
Rate of dust accumulation (mg/sq. cm/month)	Polluted	0.731	0.514		0.623*
	Control	0.103	0.065		0.084*
	Mean	0.417*	0.289*		
Leaf surface area (sq. cm)	Polluted	304.62	281.84	353.03	313.16*
	Control	352.24	366.43	455.61	391.43*
	Mean	328.43^{a}	324.14^{a}	404.32^{b}	
Leaf area index (LAI) – dimensionless quantity	Polluted	0.68	0.62	0.76	0.69*
	Control	1.53	1.48	1.89	1.63*
	Mean	1.106^{a}	1.048^{a}	1.324^{b}	
LAD	Polluted	56.51	67.42		61.97*
	Control	130.89	165.03		147.96*
	Mean	93.70*	116.23*		
Water potential (MPa)	Polluted	–	–2.68	–0.249	1.46*
	Control	–	–1.78	–0.348	1.07*
	Mean	–	–2.233*	–0.299*	
Photosynthetic rate (μmol m^{-2} s^{-1})	Polluted	–	4.0	3.7	3.85*
	Control	–	8.7	7.3	8*
	Mean	–	6.35*	5.5*	
Transpiration rate (μmol m^{-2} s^{-1})	Polluted	–	0.05	5.23	2.64*
	Control	–	0.29	0.42	0.36*
	Mean	–	0.17*	2.82*	

*Significantly different at 5% levels. Values with the same superscript do not differ between themselves.

to those in the control plot. The teak trees under particulate pollution started shedding their leaves by mid-November, compared to mid-December in case of the control site. The setting of new flushes of leaves was delayed in the polluted site than in the control plot by 45 days. This reduces the active growing season for trees in the polluted region by 77 days, in comparison to those which grow in a stress-free environment. According to Klumpp *et al.*[6], growth analysis of seedlings exposed to pollution demonstrated that a change of the relationship between aboveground and belowground plant parts was the most obvious effect of air pollution and soil contamination. The reduced LAD in the polluted plot in comparison to the control plot could play a direct role in the growth of *T. grandis* when exposed to particulate pollution. Tiwari *et al.*[2] observed that pollution leads to reduction in leaf area and leaf number, which may be due to decreased leaf production rate and enhanced senescence. The reduced leaf area can result in reduced absorbed radiation and subsequently in reduced photosynthetic rate and thus an overall decline in productivity.

Data indicate statistically significant difference between polluted and control sites in terms of height and girth. The morphology of trees at both the control and polluted sites differed greatly even though both plantations were established at the same time. The overall growth of trees was visibly stunted in the polluted site, compared to the control site. The mean height of teak trees at the polluted site was 9.7 m compared to 16.5 m at the control plot. The average girth of trees in the control plot (101.6 cm) was almost double that in the polluted plot (50.2 cm). Declining vigour of sensitive trees to particulate pollution has been attributed to reduction in needle longevity, size, increased respiratory activity and altered translocation patterns[7]; similar is the case with teak according to the present study. Pollutants can cause leaf injury, stomatal damage, premature senescence, decreased photosynthetic activity, disturb membrane permeability, and reduce growth and yield in sensitive plant species[2]. Difference in LAI between control (1.63) and polluted (0.69) plots was significant. These were significantly different between different seasons too. It was highest for the control plot during monsoon and least during summer in the polluted plot (Table 1).

Leaf texture of *T. grandis* is rough and hairy leading to greater dust accumulation compared to tree species with smooth leaf texture. Chaturvedi *et al.*[8] observed a decline in leaf area by 9%, chlorophyll content by 26%, and photosynthetic rate by 49% in *T. grandis* due to the effect of dust load, suggesting that this species is not suitable for sites having high dust loads. *T. grandis* was rated to be medium in ability to capture dust by Shrivastava and Sharma[9].

The xylem water potential of *T. grandis* in polluted plots was significantly lower at –2.68 MPa compared to –1.79 MPa in the control plot during summer. The water potential tended to be lower during monsoon season in both the plots. The lower water potential observed during summer in the polluted plot corresponds to high dust load on the leaf surface (Table 1), whereas the higher water potential during monsoon corresponds to low dust load during that season. In addition to pollution, moisture-limited conditions of Walayar during summer season may also cause lower water potential during summer. Sazonova and Olchev[10] observed that industrial pollution affects the water-conducting systems of the trees, that in turn may also cause variability in water potential of the affected trees. The rate of photosynthesis in *T. grandis* decreased with an increase in the pollution load (Table 1). The photosynthesis of *T. grandis* was lower when exposed to particulate pollution (3.85) than when growing in pollution-free conditions (8.00). Photosynthesis is one of the most stress-sensitive processes in plants and can be completely inhibited by stress before other symptoms of stress are detected[11]. Up to 25% decline in photosynthetic rate has been reported due to cement dust pollution[12]. Moreover, cement dust deposited over the surface of the leaves interferes with absorption of light; this in turn causes reduction in photosynthesis[13]. Furthermore, possible decrease in the concentration of chlorophyll and chloroplast in the leaves of trees growing in areas affected by cement dust pollution has been reported by Nanos and Ilias[14]. Thus particulate pollution load leads to a decrease in the photosynthesis affecting biomass assimilation in terms of reduced specific leaf area and plant height[15].

The transpiration was maximum during monsoon in the polluted plots (5.23), and least during summer (0.05) in the same area (Table 1). The transpiration rates were less erratic in the case of control plot, which was consistently low irrespective of season. Ambient levels of air pollution affect stomatal conductance and photosynthesis[16]. However, results in this context have not been quite consistent as both increase[17] and decline[18] in transpiration have been noticed with increased dust load. Rate of transpiration is determined by the efficiency of opening and closing processes of the stomata of individual plant species[19]. Particulate pollutants block the stomatal opening and cause mechanical injury to the guard cells. For efficient transpiration to take place, general freshness of leaf is critical which is lacking in particulate polluted sites. These pollutants lead to external foliar anomalies, which results in overall decline in transpiration efficiency of the stands affected by particulate pollutants[20]. Thus, the particulate pollution dust leads to reduced transpiration in the affected trees during summer season. However, during monsoon season when the effect of particulate pollution is least, transpiration was significantly high in polluted plot in comparison to control plot. During this period, factors other than particulate pollution may be affecting the transpiration of *T. grandis*. According to Wang *et al.*[21], atmospheric pollutants had minor effects on transpiration, while majority of variance in transpiration was by the joint effects of heat and water variables.

The present study reveals that *T. grandis* is negatively affected by particulate pollutants deposited on its leaf surface. Though *T. grandis* is a good barrier for pollution control in the areas with dust load, its deciduous character makes it ineffective during dry spells. The deciduous character is prolonged in the case of trees exposed to particulate pollution load. Even though *T. grandis* has high potential to trap the particulates on its leaf surface, it cannot function as the sole vegetational barrier against particulate pollution, especially during summer season. So it is important to couple it with an evergreen species which possesses a high particulate pollutant trapping potential.

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