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Original Research Paper

Patterns of Dust Retention by Urban Trees in Oasis Cities

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ABSTRACT

Dust pollution in Oasis cities located in arid areas affect residents' body, life and work in long term . The present study examined dust deposition on single leaves of *Populus alba* L. var. *pyramidalis* (Bunge) at various heights (1m, 2m, 4m), analysed dust particle size distribution and its contents in arid area city-Aksu, northwest China. The results showed that the amount of dust retained per leaf area of *Populus alba* L. var. *pyramidalis* (Bunge) differed significantly between sites, as follows: CAT>IA>P>RA>SFA; Leaves at a height of 1 meter retain the most dust compared with other two heights, as follows: 1m > 2m > 4m. Dust particles larger than PM10 account for more than 90% of all dust particles in all the sites and the dust accumulated on tree leaves is mainly of local urban origin. The variation of heavy metal concentrations in different sites is significant.

INTRODUCTION

The adverse effects of anthropogenic particulate matter (PM) on human health have been widely documented within the recent literature (Bousquet et al. 2003, Urch et al. 2005, Romieu et al. 2002, Annette et al. 2012), but very little attention has so far been given to the possible adverse effects on human health of naturally occurring particulates such as PM emanating from dust storms. As one of the naturally occurring forms of atmospheric pollution, dust mainly exists in three forms: dust-fall (diameter $\geq$ 10 µm), total suspended particles/TSP (diameter $\leq$ 100µm) and repairable particles/PM10 (diameter $\leq$ 10 µm); these comprise the primary atmospheric pollutants in many cities around the world (Langner et al. 2006, 2011). China's daily air quality report monitors PM_{10} and calculates Air Pollution Index (API) in accordance with the national standards, which are used as indicators of the pathological effects of dust on the human body (Kang et al. 2002). PM concentrations within the size range of 84 µg/m^3 to 600 µg/m^3 seem to be associated with the greatest impact on human health in terms of their mean daily concentration (Hwang et al. 2008). In central China, dust events were found to be a risk factor for respiratory and cardiovascular diseases, based on a 3-day lag between events and daily hospital admissions (Cheng et al. 2008). On the Caribbean island of Trinidad, reduced visibility due to increased Saharan dust cover from 'not dusty' (visibility 16 km) to 'very dusty' (visibility 7 km) was temporally associated with an increased daily hospital admission rate from average 7.8 patients to 9.25 when climate variables such as barometric pressure and humidity were kept constant (Gyan et al. 2005). More recently, it was shown that paediatric hospital admissions increased for up to 7 days following peak atmospheric dust concentration (Florence et al. 2013).

To reduce the health risks for urban population, we should control pollutant sources and reduce their effects when particulates are dispersed. Vegetation, as the lung of the city, can absorb particulate matter because dust adheres to leaf surfaces, thereby reducing the impact of air pollution on people and the ecological environment of cities (Beckett et al. 2000, Ottelé et al. 2010). Vegetation can improve air quality by absorbing airborne particulates in metropolitan regions (Prajapati & Tripathi, 2008). Trees can take up more pollution than shorter vegetation, because of their larger leaf areas and the air turbulence created by their structure (Beckett et al. 2000a). As a result of their rough, hairy and sticky leaf structure, trees have an obvious purifying effect, filtering dust pollutants by interception and absorption (Shi et al. 2003, Kang et al. 2002). The capacity for plant species to trap atmospheric particulates is determined by the characteristics of the leaf surface (Halik 2003, Thorsteinsson et al. 2011). However, the dust retention and adsorption period of tree leaves is limited, and is usually affected by rainfall, strong winds and dust storms. Generally, 15mm of rainfall can wash away the remaining dust on leaves, thereby completing one cycle and beginning the next dust-retention cycle. Therefore, the dust retention effect of plant leaves is cyclical, continuously transferring atmospheric dust to the ground; plants thereby provide a very obvious environmental purification function by reducing atmospheric pollutants (Ghafghazia et al. 2011). Liu (2006) suggested that select native and wild species to ensure the safety of the ecological environment.

The present study examined dust deposition on single leaves of *Populus alba* L. var. *pyramidalis* (Bunge) at various heights (1m, 2m, 4m). These data were used to estimate the quantity of dust deposited on an entire tree. The characteristics of the removed dust particles were analysed to evaluate the role of *Populus bolleana* Lauche in removing atmospheric dust in urban areas. The study addressed the following questions: How much dust can one unit of *Populus bolleana* leaf remove under natural conditions, and how does this vary according to site and leaf height? How does the dust particle size distribution vary between sites? Where does it come from? The results will inform the selection of species and planting design in order to maximize the removal of particulates from urban air.

MATERIALS AND METHODS

Field conditions and plant material: Aksu is located in southwest Xinjiang (E39°30’-41°27’; W79°39’-82°01’) north-west of Tarim basin, on the northern edge of the Taklimakan desert. The average altitude is 1114.8m, average annual temperature is 9.9-11.5°C, average annual precipitation is 43.9-65.3mm, annual evaporation is 1950-2600mm, average relative humidity is 47-56%, and dryness is 4.0-16.0. The area is typical of Oasis cities in arid areas, having a dry climate, scarce precipitation, and frequent dusty conditions. Approximately 8380 km^2 of Aksu is desert, occupying 45.62% of the total area (18369.9 km^2) (Statistical Yearbook of Aksu 2011). A northwest wind prevails throughout the year, especially in spring and summer. There are approximately 20 days per year with wind speed greater than 17m/s, and the maximum wind speed is 24m/s. We selected *Populus alba* L. var. *pyramidalis* (Bunge) as the object of this study, which is commonly used in urban greening projects in Aksu.

Populus alba var. *pyramidalis* is a variant of *Populus alba*, and is commonly used for greening and shelterbelt. Leaf shape is oval or elliptical, the front side is smooth, back side is hairy; it is drought tolerant; native to arid areas; and is widely distributed in Central Asia, the Balkans, Europe, and the northern provinces of China, especially in Xinjiang (Han 2006).

Analysis of dust particles: We collected leaf samples from trees and dust samples from non-vegetated areas near the selected tree with iron containers. After field collection, samples were stored in plastic bags (for leaf) and iron containers (for dust) at room temperature in the laboratory. Dust was washed from the leaf surfaces with water. Filters were weighed before and after filtration by electronic scales with an accuracy of 1μg (PTX-FA-210, Shanghai). The dust-collecting potential of each individual leaf was measured according to surface area, using a laser leaf area meter (CI-203, USA). The average weight of dust retained per unit leaf area was = dust weight (removed from leaves)/total leaf area. The sediment washed from the leaves and the dust samples collected from the non-vegetated sites were analysed by a laser particle size analyser (Microtrac S3500, USA).

Field design and statistical analysis: We combined field investigation with laboratory testing to analyse the different dust-retention abilities of leaves collected from a tree species used for urban greening. The methodology was as follows. Selection of test areas: We selected five sampling sites within the Aksu study area. Each site was plotted in relation to the various functional areas (industrial area, commercial transportation area, residential areas, parks, suburban shelter, and forest area), greening types, and their distribution within the city.

Five sites were selected in Aksu urban area and Ke Ke Ya shelterbelt forest area: 1. Commercial transportation area: Cultural Centre, No. 8 Xi Da Jie Road; 2. Residential area: No. 5 Jiao Yu Road, Aksu TV Station Courtyard; 3. Industrial area: Cement factory, No. 9 Nan Jiao Road; 4. Park: Dao Lang Park, Xi Da Jie Road; 5. Suburban shelter forest area: Ke Ke Ya Forest Management Station. Healthy and similar leaf samples were collected from mature plants. Sampling began in 05/2013 and finished in 06/2013. At each site, 2 to 3 *Populus alba* trees were selected and leaf samples were collected from each tree at heights of 1m, 2m and 4m. All the field work was conducted on sunny mornings with little wind, and metrological parameters were recorded by a portable meteorograph (M307592/NK4000). Data were analysed via analysis of variance (ANOVA) using SPSS (version 15.0, Software Co., USA), with the level of significance set at $p<0.05$.

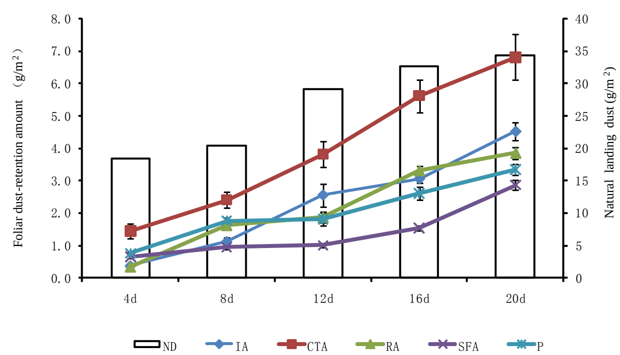

Fig.1: Average dust weight retained per unit leaf area at different sites.

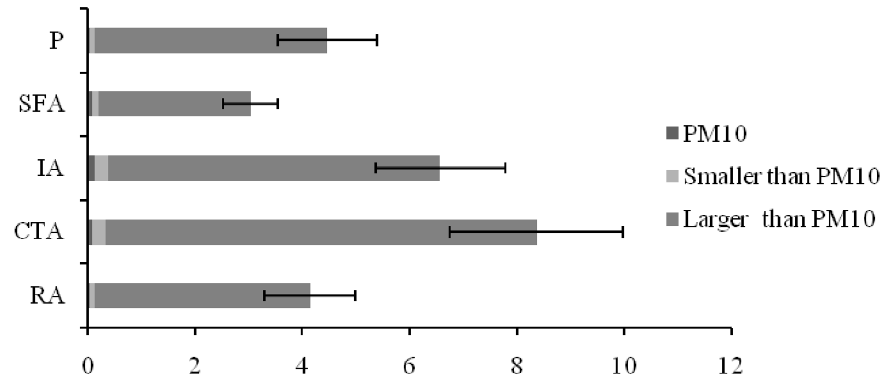

Fig. 2: Characteristics of dust particles captured by leaves.

RESULTS

Differences on sites: The average dust concentration on the sampled leaves was significantly correlated with site. As seen in Fig. 1, the trees located in the commercial transport area (CTA) retained the highest amount of dust per unit leaf area, at 8.36 g/m^2, followed by the industrial area (IA); the results for the park (P) and residential areas (RA) are similar to each other, differing only by 0.32 g/m^2; the Shelter forest area showed the lowest dust retention, at 3.04 g/m^2. Dust retention by leaf area of *Populus alba* var. *pyramidalis* followed the sequence CAT>IA>P>RA>SFA and differed significantly between sites.

The variations between the five sampling areas showed three distinct groups. The first group comprises the residential area; the second group comprises the commercial transport area and industrial area; the third group comprises the shelter forest area and park. Based on these three categories, there were significant inter-group differences but non-significant intra-group differences.

Differences on height: Table 1 shows the dust retention results for leaves collected at the three sampling heights. The leaves at a height of 1m retain the most dust > those at 2m height > 4m height; the same pattern is observed at the different sites. For example, at the CTA site, the weight of dust per unit leaf area was 12.46g/m^2 (1m), 10.37g/m^2 (2m), and 8.6g/m^2 (4m). Differences are statistically significant between different heights.

Table 1: Average weight of dust retained per unit leaf area at different heights and sites.

	1m	2m	4m
RA	8.14±0.25a	5.27±0.22b	4.14±0.14c
CTA	12.46±0.66a	10.37±0.57b	8.6±0.60c
IA	13.48±0.31a	9.74±0.49b	1.46±0.29c
SFA	4.99±0.16a	3.21±0.18b	0.78±0.08c
P	5.47±0.24a	4.35±0.19b	1.27±0.45c

Letters a–c indicate significant differences between three different heights, $P < 0.05$

Dust particle distribution: First, the particulate matter washed from the leaf samples was classified according to size as: Smaller than PM10; PM10; larger than PM10. Unexpectedly, material larger than 10 μm was much more common than other two categories as shown in Fig. 2. The highest proportion of PM_{10}, 3% (based on the number of individual particles) was found at the SFA site, compared with 2% at IA and only 1% at the three other locations. Particles > PM10 accounted for 97% at the RA and P sites; and 96%, 94% and 93% at the CTA, IA and SFA sites, respectively.

At the CTA, IA, RA, P and SFA sites, the curve representing the dust particle size distribution peaked at 248.9μm, 296.0μm, 296.2μm, 296.0μm and 31.11μm, accounting for 10.61%, 6.73%, 7.66%, 8.57% and 11.05% of all dust measured, respectively. The distribution curves for the CTA, RA, and P sites are bimodal, with the first mode of 74~150μm, accounting for 4~7%; and the second mode of 209~352μm accounting for 6~10% of the content. The SFA site has only one mode, in the range 22~37μm, representing 9~11% of the total dust volume. The two modes of the distribution curve for the IA site are greater than the corresponding values for CTA, RA, and P: the first at 104-296μm, 3%~6%; the second at 591~995μm, 6-7%.

The three curves representing sites IA, RA and P have approximately the same peaks, around 296.0μm; the CTA distribution has a very similar peak of 248.9μm; however, at the SFA site, the most common dust particle diameter is only 31.11μm, approximately one-eighth the size of particles at the other sampling sites (Fig. 3).

The average dust weight and the most common dust particle size had a correlation coefficient of 0.425, which was not significant at the 0.05 level (Table 2).

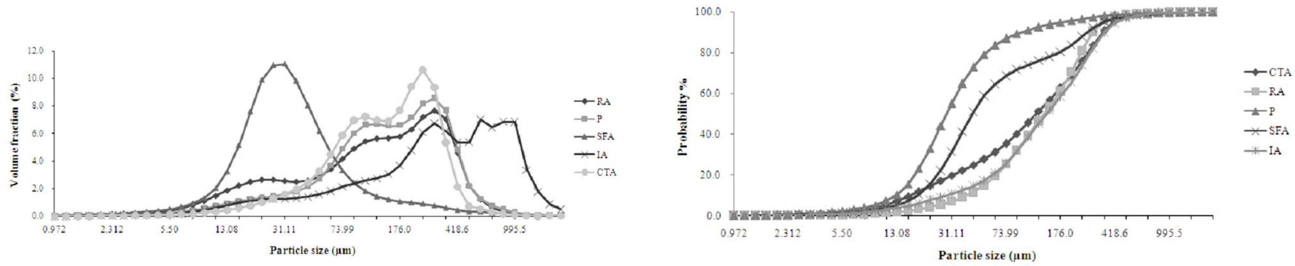

Fig. 3: Frequency curve and cumulative probability curve of dust particles at different sites.

DISCUSSION AND CONCLUSIONS

Differences between locations and heights: Dust retention by *Populus alba* var. *pyramidalis* differed significantly between the various functional areas. The amount of dust retained per unit leaf area was greater at the commercial transport area and industrial area than at the park, residential area, and suburban shelter forest area. The reason is that greater volumes of atmospheric pollutants are emitted in the industrial area and transportation hub area than in the other areas. Most of these particulates settled-out in the immediate or adjacent area, due to their mass; a small proportion was transported by wind action and deposited within the other functional areas, such as residential areas and parks. The Kokyar suburban shelter forest area was selected as the clean area in our study. It showed little effect of pollutants discharged in the city, resulting in the least dust deposition per unit leaf area. Prusty (2005) found that dust-fall load was positively correlated with traffic flow, and Ravindra et al. (2008) reported that 80% of particulates in urban air derive from automobile exhaust. Heavy traffic, a large volume of automobile exhaust and large-scale construction are the main reasons for the greatest accumulation of particulates found on tree leaves in the Aksu city area. Plant leaves are affected mostly by rainfall, strong winds, and dusty weather; generally, 15mm rainfall can wash away the dust accumulation on tree leaves, ready for the next dust retention cycle. During the sampling period, there was not 15mm precipitation; generally, single precipitation events exceeding 15mm are rare in Aksu, and average annual rainfall is only 43.9-65.3mm. Therefore, the main factors influencing dust retention are dusty weather and man-made washing. In the Ke Ke Ya suburban shelter forest area, dust accumulated on plant foliage is not consolidated, and is easily dislodged in windy weather, which further contributes to the lowest accumulation of dust on leaves at this site.

Liu (2007) pointed out that, for deciduous trees and liana species, dust retention is negatively correlated with sampling height, whereas for shrub species, dust retention is positively correlated with height. Our findings confirm those of Liu, in that dust retention by leaf height followed the sequence: 1m >2m >4m. This indicates that most of the dust particles are airborne at heights of less than 4m, are deposited on the leaf surface due to gravity and wind action, or temporarily fall towards the ground.

In Aksu, it can be concluded that the dust accumulated on tree leaves is mainly of urban origin, city dust, particle matters smaller than 840ìm, generally attached to and deposited on the Urban surfaces (road, bridge, street, square), the exposed surface of the building, non-curing adhesive; and is easy dislodged by surface runoff, precipitation and wind (Zhu, 2003). City dust is the main resources and destination of suspended atmospheric particulates in the atmosphere. Fergusson and Ryan (1984) found that element content in city dust increases with decreasing particle size. This indicates that dust particles in Aksu city contain few elements, although the dust retention level is high, which mostly (>90%) including big particles (>PM_{10}). The bigger particles have less adverse effect on the human body than smaller particles (like $PM_{2.5}$) which have the potential to penetrate deeper into the lungs. However, urban dust raised between 1~5m repeatedly (Liu et al. 2007), stimulate human respiration continuously, affecting human body, life and work in long term. *Populus alba* var. *pyramidalis* can play a significant positive role in absorbing and removing city urban dust from the atmosphere.

Findings and Implications

1. The amount of dust retained per leaf area of *Populus alba* L. var. *pyramidalis* differed significantly between sites as follows: CAT > IA > P > RA > SFA.
2. Leaves at a height of 1 meter retain the most dust compared with other two heights, as follows: 1m > 2m > 4m. The same pattern was found at all the sites.
3. Dust particles larger than PM_{10} account for more than 90% of all dust particles at the CTA, IA, SFA, RA and P sites, with modes between 22μm and 995μm. In Aksu, it is concluded that the dust accumulated on tree leaves is mainly of local urban origin.

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Table 2: Average dust weight and most common particle size.

0Item	RA	CTA	IA	SFA	P
Average dust weight captured by unit leaf area (g/m^2)	4.14	8.35	6.57	3.038	4.46
The most common dust particle size (μm)	296.2	248.9	296.0	31.11	296.0
Coefficient			0.425		

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