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Original Research Paper

Effects of Landscape Tree Species and Their Arrangement on $PM_{2.5}$ Sedimentation - A Case Study of Beijing, China

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ABSTRACT

$PM_{2.5}$, which refers to particles less than 2.5 µm in diameter, pose great health risks. Previous studies have mainly focused on the relationship between land utilization and air quality. Few studies have discussed the effects of landscape tree species on $PM_{2.5}$ sedimentation and explored reasonable tree species arrangement for $PM_{2.5}$ prevention. This study considered the polluted Beijing in China as the study site. This study investigated the $PM_{2.5}$ sedimentation data of 10 shrub and 11 arbor species to understand the $PM_{2.5}$ holding capacities of the landscape tree species. This study also obtained $PM_{2.5}$ concentration data from 35 air quality monitoring sites. The results of linear regression analysis showed that (1) a closely linear relationship exists between $PM_{2.5}$ concentration from air flow and $PM_{2.5}$ sedimentation of various tree species in different seasons and sampling sites, and that (2) shrub trees possess better $PM_{2.5}$ holding capacities than arbor trees in urban and heavy traffic areas, whereas arbor trees exert obvious effects on preventing $PM_{2.5}$ pollution in rural areas. Thus, the proportion of shrub trees should be reduced in urban and heavy traffic regions, whereas that of arbor trees should be increased in rural areas. This study attempted to solve air pollution through landscape tree arrangement for $PM_{2.5}$ sedimentation. The results of this study could serve as a guide for landscape tree species arrangement and plantation in Beijing and other cities.

INTRODUCTION

Particulate matter (PM) refers to air particles that may be large or dark enough to be seen as soot or smoke or so small that they can only be detected individually under an electron microscope. Many manmade and natural sources emit PM directly or emit other pollutants that react in the atmosphere to form PM. These solid and liquid particles have a wide range of sizes. $PM_{2.5}$, which refers to air PM less than 2.5 µm in aerodynamic diameter, pose great health risks (Wu et al. 2015). $PM_{2.5}$ are produced from vehicle exhaust, marine aerosols, coal and fuel oil combustion, burning of agricultural wastes, paved road dust, and secondary sulfates, etc. (Pui et al. 2014). The $PM_{2.5}$ pollution in China has caused widespread concern. Large cities such as Beijing and Shanghai have suffered from hazes in years, causing certain social, environmental, and ecological losses (Sun et al. 2006). Thus, this problem in China is too urgent to ignore, considering its fast urbanization and population explosion in the coming decades (Chen et al. 2007).

High $PM_{2.5}$ concentrations are associated with increased rates of cardiovascular and respiratory diseases (Dockery et al. 2009, Pope et al. 2006), which result in death or serious harm. Thus, strategies to decrease $PM_{2.5}$ concentration to reduce its adverse impacts have become a hot issue among researchers (Wu et al. 2015).

Recent studies have mainly focused on the source composition, measurement, simulation, and health risk assessment of $PM_{2.5}$ (Sun et al. 2006, Howell et al. 2000, Saveraid et al. 2001, Shao et al. 2004, Wang et al. 2007, Escobedo et al. 2009, Boyd et al. 2010, Wu et al. 2011, Santos-Filho et al. 2012, Schindler et al. 2013, Yu et al. 2014, Xie et al. 2015) and attempted to determine feasible measures to reduce the negative effects of $PM_{2.5}$. Several studies have also explored the relationship between air pollution and land use (Wu et al. 2015, Pui et al. 2014, Xie et al. 2015, Uuemaa et al. 2015, Kashima et al. 2009, Connors et al. 2013, Tan et al. 2013, Li et al. 2013, Carter et al. 2014, Zhou et al. 2014, Shen et al. 2014). However, few studies have determined the relevance of landscape trees within the city and their $PM_{2.5}$

prevention effects, as well as the reasonable tree arrangement in city landscape planning (Escobedo et al. 2009, Santos-Filho et al. 2012, Ross et al. 2007, Matsuda et al. 2010, Morani et al. 2011, Hwang et al. 2011, Tallis et al. 2011, Zhang et al. 2011).

Compared with other pollutions such as noise and water, $PM_{2.5}$ poses a greater threat to China; thus, studies on $PM_{2.5}$ are worth exploring. Researchers and designers of landscape science should focus on the influence of tree species rather than different landscape patterns on air pollution (Wu et al. 2015, Howell et al. 2000, Tang et al. 2007). One reason is data can be simply and timely collected; other possible reasons may include the appropriateness of method (Sun et al. 2006, Chen et al. 2007, Dockery 2009, Shao et al. 2004, Wang et al. 2007, Ross et al. 2007, Yang et al. 2005, Henderson et al. 2007, Tang et al. 2007).

Urban landscape trees are used for several purposes, including wind prevention, aesthetics and economic benefits of ecological greening. Thus, the $PM_{2.5}$ holding ability and arrangement of urban landscape trees, especially those in China, must be clarified to understand the relationship between landscape tree species and their effects on air pollution (Boyd et al. 2010, Matsuda et al. 2010, Morani et al. 2011, Hwang et al. 2011, Lee et al. 2009, Buyantuyev et al. 2010, Schwarz 2010, Gromke 2011, Gulliver et al. 2011).

The present study primarily aims to examine the effects of landscape trees on $PM_{2.5}$ pollution in Beijing, China's capital. This city was selected as the study site because of its limited green space (Yu et al. 2014). The results of this study may serve to improve urban landscape planning and management, and discover measures for addressing air quality problems in the future.

MATERIALS AND METHODS

Study area: Beijing is located in the northeast of the North China Plain (about 115°250'-117°300'E, 39°280'-41°250'N) with a population of approximately 20.693 million and a total area of 16,410.54 km^2. The climate in this city belongs to a continental monsoon climate with apparent seasons (Wu et al. 2015, Shen et al. 2014). The average temperature is 12.3°C, and the annual precipitation is approximately 570mm. In recent years, Beijing has been undergoing rapid urbanization, which is accompanied by frequent haze events and high pollutant concentrations in this city.

Data acquisition: (1) The $PM_{2.5}$ concentration of 35 monitoring sites (including transportation pollution sampling sites, inner city pollution sampling sites, regional background control sites, and suburb pollution sampling sites) in Beijing was obtained from the website of the Beijing Environmental Monitoring Center (http://zx.bjmemc. com.cn/) (Fig. 1). We used March, April and May; June, July and August; September, October and November; and December, January and February to represent spring, summer, autumn and winter, respectively. Data from 2015 were collected. (2) The $PM_{2.5}$ sedimentation of 10 shrub and 11 arbor trees was obtained using a portable hand-hold $PM_{2.5}$ detector (Lighthouse, 3016IAQ, USA). We measured the 0, 15 and 30 cm $PM_{2.5}$ sedimentation values of shrub trees and 0, 30 and 60 cm $PM_{2.5}$ sedimentation values of arbor trees (Equations (1) and (2)). Each spot was sampled three times (Equations (3) and (4)). The comprehensive $PM_{2.5}$ sedimentation value of each pattern (landscape tree species arrangement) was calculated below (Equations (5), (6), (7) and (8)). Fig. 2 shows that $PM_{2.5}$ particles were carried by wind. According to particle size (>0.5 mm movement status: creep; 0.05–0.5 mm saltation; <0.05 mm suspension), the mass of the $PM_{2.5}$ particles flew in air. Then, $PM_{2.5}$ particles concentrated to the ground and again were blown up repeatedly. Moreover, landscape tree species have certain abilities to prevent $PM_{2.5}$ pollution, and $PM_{2.5}$ can be deposited within the trees. Such a movement process can be referred as sedimentation. However, $PM_{2.5}$ particles remain within the forest and cannot be effectively prevented because of the loose structure of the forest and little wind. Thus, shrubs could theoretically hold the fine particles within the trees, whereas arbor trees could stop particles in the windward side. To verify this theory, experiments were conducted to prove the ideas above.

$$y_s = \frac{h_1 y_{1PM2.5} + h_2 y_{2PM2.5} + h_3 y_{3PM2.5}}{3} \quad ...(1)$$

Where y_s is the $PM_{2.5}$ sedimentation value of shrub trees, h_1 is 0 cm, h_2 is 15 cm, h_3 is 30 cm, and $y_{1,2,3}$ is the measured $PM_{2.5}$ sedimentation value of shrub trees.

$$y_a = \frac{h_1 y_{1PM2.5} + h_2 y_{2PM2.5} + h_3 y_{3PM2.5}}{3} \quad ...(2)$$

Where y_a is the $PM_{2.5}$ sedimentation value of arbor trees, h_1 is 0 cm, h_2 is 30 cm, h_3 is 60 cm, and $y_{1,2,3}$ is the measured $PM_{2.5}$ sedimentation value of arbor trees.

$$y_{s\text{-}c} = \frac{y_{s1} + y_{s2} + y_{s3}}{3} \quad ...(3)$$

Where $y_{s\text{-}c}$ is the calculated $PM_{2.5}$ sedimentation value of shrub trees, and $y_{s1,2,3}$ is the $PM_{2.5}$ sedimentation value of shrub trees (according to the calculation result of Eq. (1)).

$$y_{a\text{-}c} = \frac{y_{a1} + y_{a2} + y_{a3}}{3} \quad ...(4)$$

Where $y_{a\text{-}c}$ is the calculated $PM_{2.5}$ sedimentation value of arbor trees, and $y_{a1,2,3}$ is the $PM_{2.5}$ sedimentation value of

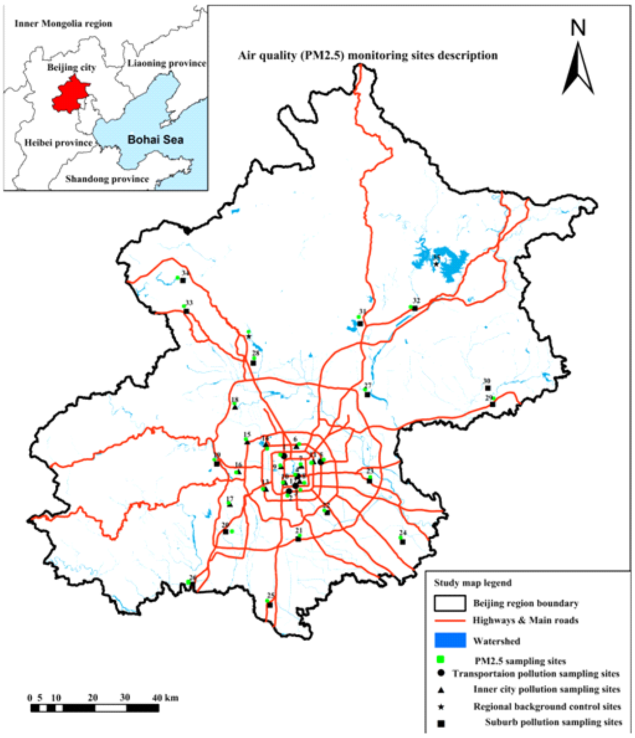

Fig. 1: Classification and distribution of air quality monitoring sites in Beijing area. Note: this original image was from research paper, doi:10.1371/journal.pone.0142449 (Wu et al. 2015)

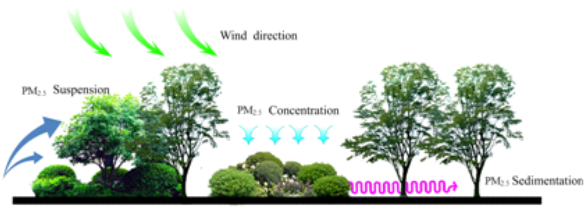

Fig. 2: Sketch map of $PM_{2.5}$ movement track.

arbor trees (according to calculation result of Eq. (2)).

$$y_{original} = \frac{x_{1area} y_{scPM\,2.5} + x_{2area} y_{acPM\,2.5}}{x_{total-area}} \quad ...(5)$$

Where $y_{original}$ is calculated by the $PM_{2.5}$ sedimentation value in existing pattern, and x_{narea} is the area occupied by each tree species, n=1, 2, 3….

$$y_{optimized} = \frac{x_{1area} y_{scPM\,2.5} + x_{2area} y_{acPM\,2.5}}{x_{total-area}} \quad ...(6)$$

Where $y_{optimized}$ is the optimized $PM_{2.5}$ sedimentation data. It also takes the following form:

$$y_{optimized} = \frac{x_{1area} y_{sc1PM\,2.5} + x_{2area} y_{sc2PM\,2.5}}{x_{total-area}} \quad ...(7)$$

Where $y_{ac1,2}$ is the $PM_{2.5}$ sedimentation value of shrub trees 1 and 2.

$$y_{optimized} = \frac{x_{1area} y_{ac1PM\,2.5} + x_{2area} y_{ac2PM\,2.5}}{x_{total-area}} \quad ...(8)$$

Where $y_{ac1,2}$ is the $PM_{2.5}$ sedimentation value of arbor trees 1 and 2.

Statistical analysis: The annual and seasonal average concentrations and sedimentations of $PM_{2.5}$ in 35 and 34 sites were determined. The statistical analysis includes linear analysis by using version 21.0 of SPSS software (IBM Inc. NC, USA). Simple calculations on tree arrangement were conducted using Excel (Microsoft Inc. SE, USA). Other data processing and plotting were completed with software Origin 9.0 (Origin Lab Inc., Northampton, MA, USA).

RESULTS AND ANALYSIS

Descriptive statistics: All 35 sites were valid samples during 2015. The annual average concentration in 35 sites was 83.04 μg/m^3, which was three times higher than the WHO (World Health Organization) *Level 1* Interim Target of 35 μg/m^3 (Wu et al. 2015). The maximum value of annual average concentration was 71.00 μg/m^3 in the regional background control sites, 118.00 μg/m^3 in the transportation pollution sampling sites, 107.36 μg/m^3 in the inner city pollution sampling sites, and 109.36 μg/m^3 in the suburb pollution sampling sites, whereas the minimum value was 22.64 μg/m^3 in the regional background control sites, 71.00 μg/m^3 in the transportation pollution sampling sites, 79.00 μg/m^3 in the inner city pollution sampling sites, and 75.00 μg/m^3 in the suburb pollution sampling sites. Fig. 3 shows that the $PM_{2.5}$ concentration in all seasons was persistently increased. The average concentrations in the four seasons were 69.54, 80.46, 89.87, and 100.67 μg/m^3, respectively. The average peak concentrations in spring, summer, autumn, and winter were 81.21, 97.47, 107.16, and 117.74 μg/m^3, respectively. Significant differences were observed between different seasons and sites (P<0.01) (data not shown). The spatiotemporal discrepancies of $PM_{2.5}$ concentration in Beijing were evident.

$PM_{2.5}$ concentration and sedimentation correlation analysis: The relationship between all (data include seasons and sites) $PM_{2.5}$ concentration (sources) and $PM_{2.5}$ sedimentation (sinks) was characterized through linear correlation analysis (Fig. 4). The result indicates that the $PM_{2.5}$ sedimentation of plants is closely related to the $PM_{2.5}$ concentration of air

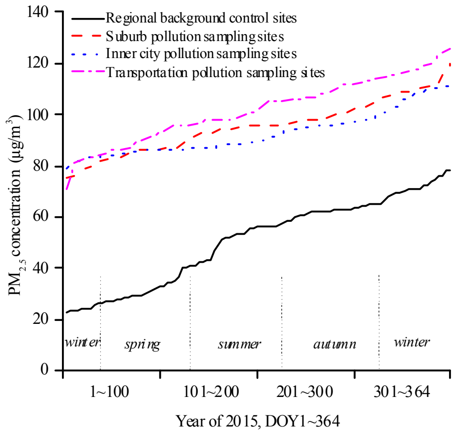

Fig. 3: Seasonal pattern of all categories of 35 sites.

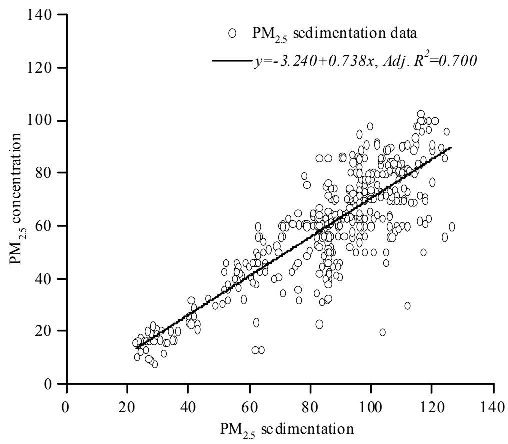

Fig. 4: Correlation between concentration and sedimentation of $PM_{2.5}$ analysis.

flow (Adjust R^2 value equals to 0.700). In other words, the trees have effective $PM_{2.5}$ holding capacities to prevent $PM_{2.5}$ pollution.

Effects of landscape tree species on $PM_{2.5}$ sedimentation: To investigate the abilities of the different tree species for $PM_{2.5}$ sedimentation, we surveyed typical trees (10 shrubs and 11 arbor trees) in all seasons and sites. The obtained results (Table 1) indicate that the arbor trees have a greater $PM_{2.5}$ sedimentation capability than the shrub trees in all seasons and that minimal differences can be found between the shrubs but not between the arbor trees. Among the shrub trees, *Syringa reticulate* serves in $PM_{2.5}$ prevention, whereas *Ulmus pumila* participates in $PM_{2.5}$ sedimentation. We further investigated four air quality monitoring sites. As given in Table 1, the shrubs and arbor trees display no significant differences in urban and traffic sites, but arbor trees in rural areas exhibit great advantages in preventing $PM_{2.5}$ pollution. Among the shrub trees, *Forsythia giraldiana* is superior to the other trees, whereas *Ulmus pumila* is advantageous over the other tree species.

As we studied above, arbor trees can hold a mass of $PM_{2.5}$ particles in rural areas, but such an effect is not obvious in urban areas compared with shrubs. Meanwhile, their loose structure (e. g. two trees are planted in distance) renders $PM_{2.5}$ easy to float at a long time and hard to settle in the atmosphere. Thus, a persistent and widespread $PM_{2.5}$ pollution event would not be reduced.

Effects of landscape tree species arrangement on $PM_{2.5}$ sedimentation: We adjusted tree species configuration. Tree forms, specific tree structure, and other aspects were not considered because of their complexities and unpredictability. The adjusted landscape tree species are listed inTable 2. To reach the purposes, tree species arrangement was optimized on the basis of the actual demand of $PM_{2.5}$ reduction observed in the monitoring sites. As given in Table 2, the proportion of shrub trees was reduced in rural areas, whereas that of arbor trees was increased in urban areas. Finally, we compared the $PM_{2.5}$ sedimentation values between the original and optimized data (Fig. 5). The simulation results are significantly higher than the original data and air quality sampling data, especially in urban areas.

The concentration of $PM_{2.5}$ is controlled by multiple factors, such as wind, air temperature, precipitation, and traffic conditions (Nolte et al. 2001, Buczyñska et al. 2014, Du et al. 2014). The present study focused on landscape tree species pattern and attempted to give proper suggestions on their arrangement.

The results showed differences among the four seasons and sampling sites. $PM_{2.5}$ pollution is more severe in autumn and winter than in spring and summer partly because of special crop land use. In autumn, the crop could produce smoke by straw burning, either in Beijing or surrounding regions, making it significant in $PM_{2.5}$ emission. This process would last into spring of the next year. Bad $PM_{2.5}$ phenomenon also occurs in winter because of winter heating and firework setting (Wu et al. 2011, Santos-Filho et al. 2012, Schindler et al. 2013, Connors et al. 2013, Tan et al. 2013, Li et al. 2013, Morani et al. 2011, Hwang et al. 2011, Tallis et al. 2011, Zhang et al. 2011, Gulliver et al. 2011, Dzier|anowski et al. 2011, Tu 2011, Zhou et al. 2011, Li et al. 2012, Aowicki et al. 2012, Nowak et al. 2013). Different air quality sampling sites have different $PM_{2.5}$ concentrations in suburb areas, which could be a main source because of the soil or sand dust caused by wind erosion, especially in open fields, where sand storms frequently occur. However, wind is relatively small in urban areas (including traffic areas), and mass of $PM_{2.5}$ particles is prevented by high-rise buildings; such a harm is less severe. However, explaining

Table 1: Effects of landscape tree species on $PM_{2.5}$ sedimentation in different seasons and sites.

LandscapeTree species	$PM_{2.5}$ sedimentation capability (µg/m^3)					Air quality monitoring sites nearby sampling (µg/m^3)			
	Spring	Summer	Autumn	Winter	Average	CV sites	Suburb sites	Urban sites	Traffic sites
Shrub	-	-	-	-	-	-	-	-	-
Prunus × cistena	14.23±0.01	21.63±0.03	30.32±0.32	35.14±0.01	25.33	-	8.63±0.01	28.56±0.00	26.64±0.05
Hibiscus syriacus	15.62±0.03	22.61±0.01	32.46±0.21	39.41±0.01	27.52	21.32±0.31	12.63±0.01	28.62±0.03	30.64±0.45
Syzygium romaticum	16.23±0.05	23.15±0.04	33.45±0.03	40.36±0.31	28.30	22.65±0.43	13.54±0.02	29.63±0.41	32.45±0.34
Cercis racemosa	13.62±0.01	18.63±0.01	28.41±0.11	33.47±0.11	23.53	-	-	18.63±0.06	22.64±0.21
Euonymus fimbriatus	16.23±0.04	18.25±0.01	32.54±0.32	36.41±0.04	25.86	12.32±0.03	18.42±0.00	22.63±1.01	28.64±0.04
Magnolia liliiflora	16.32±0.02	22.85±0.06	35.63±0.21	38.41±0.06	28.30	-	15.63±0.05	35.23±0.54	37.42±0.00
Syringa reticulata	19.63±0.01	23.56±0.08	36.48±0.21	40.32±0.06	30.00	15.63±0.05	20.63±0.01	40.89±0.56	46.58±0.21
Cotinus coggygria	15.63±0.04	22.87±0.01	36.54±0.45	41.25±0.32	29.07	-	-	45.61±0.88	50.63±0.45
Forsythia giraldiana	16.32±0.05	22.74±0.07	33.65±0.01	37.56±0.12	27.57	16.36±0.07	20.63±0.01	52.63±0.75	58.96±2.34
Jasminum nudiflorum	16.39±0.05	26.39±0.01	37.89±0.02	40.63±0.45	30.32	-	28.96±0.00	44.63±0.32	47.89±1.23
Arbor	-	-	-	-	-	-	-	-	-
Magnolia heptapeta	18.63±0.04	30.36±0.06	68.63±0.61	84.23±1.01	50.46	30.63±0.08	40.86±0.41	30.51±0.04	27.98±0.00
Cerasus serrulata	26.36±0.04	38.95±0.03	70.86±0.56	100.63±3.09	59.20	46.63±0.32	76.56±0.21	40.63±0.07	20.74±0.01
Amygdalus davidiana	30.45±0.03	45.75±0.03	85.63±0.78	106.34±3.04	67.04	52.63±0.45	80.56±0.98	36.56±0.03	33.46±0.01
Armeniaca sibirica	22.63±0.02	20.14±0.01	50.54±0.43	86.78±0.81	45.02	37.86±0.67	86.54±1.01	42.31±0.02	25.63±0.54
Amygdalus persica	26.35±0.01	24.67±0.01	60.61±0.56	85.41±1.01	49.26	40.23±0.56	90.54±1.04	47.54±0.43	30.51±0.78
Prunus cerasifera	22.48±0.01	47.89±0.11	77.52±0.77	96.56±9.45	61.11	34.56±0.67	100.54±3.04	43.25±0.32	24.87±0.00
Cerasus cerasoides	18.47±0.01	46.93±0.31	80.65±0.78	102.64±6.01	62.17	40.63±0.32	85.64±1.04	50.64±1.01	34.65±0.04
Ludwigia hyssopifolia	20.41±0.04	50.47±0.51	79.65±0.87	94.63±4.05	61.29	33.46±0.11	77.46±6.06	68.96±3.04	40.61±0.45
Acer palmatum	23.41±0.05	61.25±0.41	88.69±0.65	114.63±6.06	72.00	39.65±0.01	84.65±3.04	65.74±2.01	50.64±0.78
Lonicera maackii	21.63±0.01	77.63±0.034	96.21±0.67	120.63±12.03	79.02	29.64±0.11	86.53±6.02	60.32±3.21	23.54±0.01
Ulmus pumila	23.56±0.012	85.63±0.91	100.41±0.34	122.41±10.45	83.00	31.25±0.56	95.41±1.03	52.63±3.03	36.54±0.05

all different variables between seasons and sites was difficult because of the complicated influences of other factors, such as meteorological factors and human interference. Nevertheless, certain and stable regularities are still presented.

Furthermore, we could determine the effect of landscape tree species on $PM_{2.5}$ directly. The linear regression model showed that landscape tree species patterns correlate with $PM_{2.5}$ concentration. The coefficient of source $PM_{2.5}$ pollution and sink landscape tree species pattern in the simple linear relationship model is 0.7 because the coefficient is positive in the model. In fact, the role of trees on $PM_{2.5}$ is easy to understand. In general, the land use type most frequently associated with $PM_{2.5}$ concentration is vegetation, followed by water body and cropland, and then bare land and construction land (Kong et al. 2010). Vegetation mainly absorbs particulate matter through leaves by dry and wet deposition to reduce ambient $PM_{2.5}$ concentration (Wu et al. 2015). Tree planning has been introduced by the Beijing municipal government as a major measure to improve air quality (Sun et al. 2006). Yang et al. 2005 used an urban forest effects model to explore the effect of urban forest on air pollution. Results showed that trees in central Beijing removed 1261.4 tons of pollutants, most of which were particulate matter. Research in 10 U.S. cities also showed similar results in that the amount of $PM_{2.5}$ removed by trees ranged from 4.7 to 64.5 tons annually, saving about 60 million dollars in healthcare costs and mortalities of New York State because of cleaner air (Nowak et al. 2013). Gromke 2011 found using a new vegetation model that trees negatively influence pollutant dispersion. Dzierzanowski et al. (2011) further focused on the various functions of different tree species on particulate matter. The results of the above studies revealed that vegetation significantly influences $PM_{2.5}$ mitigation, which agrees with the results of this study.

The percentage of specific areas could be changed to solve $PM_{2.5}$ problems thoroughly. For example, sink landscape can absorb $PM_{2.5}$, and construction land can produce particulate matter; altering their areas could increase or decrease $PM_{2.5}$ (Wu et al. 2015). According to the "Beijing urban planning project," the possibility to increase greening area or decrease construction land area is small (Wu et al. 2015). Thus, the positive role of landscape tree species configuration should be maximized to solve serious haze problems. However, few studies have investigated the effect of configuration on $PM_{2.5}$. In the present study, 10 shrubs and 11 arbor trees were selected, the $PM_{2.5}$ sedimentation capability of each tree was analyzed, and then the configuration of landscape trees to ease haze was optimized. We only focused on tree arrangement by simple calculations and concluded that shrub trees can effectively prevent fine particles in urban areas while arbor trees can significantly re-

Table 2: List of before and after landscape tree species arrangement.

Site	Original landscape tree species			Adjusted landscape tree species		
	Suburb sites	Urban sites	Traffic sites	Suburb sites	Urban sites	Traffic sites
1	-	-	A_1B_1, A_2B_2	-	-	A_1A_1, A_3A_7
2	-	-	A_5B_{10}, A_7B_8	-	-	A_5A_8, A_7A_8
3	-	-	A_3B_9, A_3B_6	-	-	A_3A_3, A_3A_7
4	-	-	A_3B_9, A_5B_6	-	-	A_3A_2, A_5A_1
5	-	-	A_5B_9, A_2B_6	-	-	A_5A_3, A_2A_{10}
6	-	A_3B_1, A_3B_4	-	-	A_3A_8, A_3A_4	-
7	-	A_5B_8, A_2B_7	-	-	A_5A_8, A_2A_5	-
8	-	A_5B_8, A_4B_5	-	-	A_5A_9, A_4A_2	-
9	-	A_8B_5, A_7B_9	-	-	A_8A_8, A_7A_9	-
10	-	A_6B_7, A_4B_8	-	-	A_6A_8, A_4A_9	-
11	-	A_4B_9, A_2B_3	-	-	A_4B_9, A_2A_6	-
12	-	A_6B_3, A_2B_6	-	-	A_6A_9, A_2B_6	-
13	-	A_7B_9, A_3B_8	-	-	A_7B_9, A_3A_8	-
14	-	A_4B_8, A_9B_2	-	-	A_4A_5, A_6A_2	-
15	-	A_6B_7, A_3B_5	-	-	A_6B_7, B_4B_5	-
16	-	A_2B_3, A_6B_8	-	-	B_2B_3, A_6B_8	-
17	-	A_5B_8, A_2B_7	-	-	A_5A_8, A_2A_9	-
18	-	A_6B_7, A_4B_6	-	-	A_6A_7, A_4B_6	-
19	A_2B_5, A_5B_6	-	-	B_2B_5, B_5B_6	-	-
20	$A_{10}B_6$, A_6B_9	-	-	$B_{11}B_6$, B_7B_9	-	-
21	A_6B_7, A_7B_6	-	-	B_5B_7, B_3B_6	-	-
22	A_5B_9, A_3B_7	-	-	B_5B_9, A_4B_7	-	-
23	A_7B_7, A_3B_1	-	-	A_5B_7, B_3B_1	-	-
24	A_7B_3, A_5B_7	-	-	B_1B_3, A_8B_7	-	-
25	A_6B_8, A_5B_7	-	-	B_6B_8, A_2B_7	-	-
26	A_7B_8, A_2B_9	-	-	B_2B_8, A_7B_9	-	-
27	A_6B_5, A_7B_8	-	-	B_1B_5, A_3B_8	-	-
28	A_4B_9, A_5B_8	-	-	B_4B_9, B_6B_8	-	-
29	A_2B_8, A_1B_6	-	-	B_2B_8, B_3B_6	-	-
30	A_6B_3, A_6B_9	-	-	A_7B_3, B_8B_9	-	-
31	A_7B_6, A_4B_3	-	-	B_2B_6, A_5B_3	-	-
32	A_5B_3, A_4B_6	-	-	A_5B_3, A_4B_6	-	-
33	A_7B_7, A_1B_7	-	-	B_1B_7, A_1B_{11}	-	-
34	A_8B_9, A_3B_6	-	-	B_8B_9, B_3B_8	-	-

Note: A_1 presents *Prunus × cistena*, A_2 presents *Hibiscus syriacus*, A_3 presents *Syzygium romaticum*, A_4 presents *Cercis racemosa*, A_5 presents *Euonymus fimbriatus*, A_6 presents *Magnolia liliiflora*, A_7 presents *Syringa reticulata*, A_8 presents *Cotinus coggygria*, A_9 presents *Forsythia giraldiana*, A_{10} presents *Jasminum nudiflorum*, B_1 presents *Magnolia heptapeta*, B_2 presents *Cerasus serrulata*, B_3 presents *Amygdalus davidiana*, B_4 presents *Armeniaca sibirica*, B_5 presents *Amygdalus persica*, B_6 presents *Prunus cerasifera*, B_7 presents *Cerasus cerasoides*, B_8 presents *Ludwigia hyssopifolia*, B_9 presents *Acer palmatum*, B_{10} presents *Lonicera maackii*, B_{11} presents *Ulmus pumila*

duce $PM_{2.5}$ concentration in rural areas. Such processes are too complex; thus, future studies should focus on these processes and provide further information in the future.

The present study analyzed data from 35 sites because the number of monitoring sites in Beijing cover all important areas. However, typical areas may have been overlooked. Moreover, the mechanisms and processes responsible for the effects of landscape tree species on $PM_{2.5}$ pollution and seasonal differences could not be clearly identified from the statistical calculations applied in this study. However, air pollution data are influenced by time and location; thus, the timeliness and stability of the results were not easily assessed. $PM_{2.5}$ is controlled by many factors that are difficult to measure (Wu et al. 2015). Xie et al. (2015) conducted a case study in 31 Chinese cities and found that $PM_{2.5}$ concentration is related to chemical components such as SO_2, NO_2, CO, and O_3. Recent research has considered meteorological factors, such as humidity, wind speed, and wind direction (Sun et al. 2006, Howell et al. 2000, Zhou et al. 2014, Dzier|anowski et al. 2011, Nowak et al. 2013). Other research focused on the spatiotemporal characteristics of the effects, the impact scale and intensity, and mechanisms of seasonal differences (Wu et al. 2015). With the rapid development of technique and data sharing around the world, potential solutions could be expected (Wu et al. 2015). Such experiments would definitely be included in our further studies and research directions.

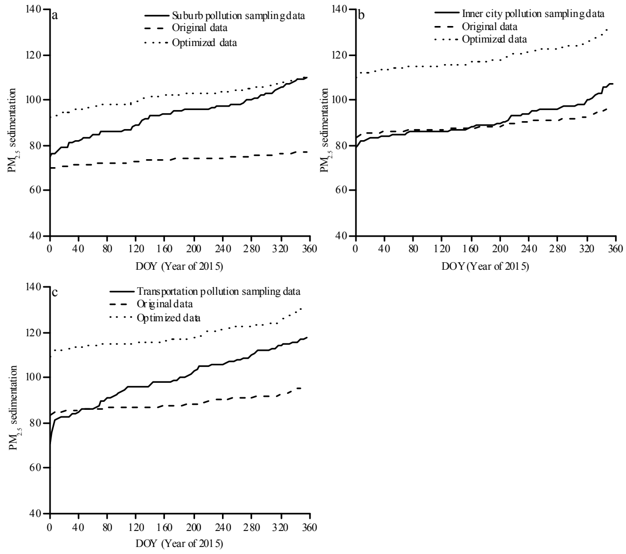

Fig. 5: Comparison of $PM_{2.5}$ sedimentation values of before and after landscape tree species arrangement.

CONCLUSION

Among all the pollution sources, $PM_{2.5}$ is the core pollutant of haze formation. These problems are faced in China, particularly in Beijing and Shanghai. To solve this increasingly problematic issue, we quantitatively investigated the effects of urban landscape tree species patterns on $PM_{2.5}$ concentration with Beijing as the study site and realized a reasonable arrangement of tree species. Our study yielded the following conclusions:

1. Vegetation can absorb particulate matter to reduce pollutants. Among all landscape tree species composition, a close relationship exists between $PM_{2.5}$ concentration from air flow and $PM_{2.5}$ sedimentation of various tree species in different seasons and sampling sites.
2. Shrub trees have greater $PM_{2.5}$ holding capacities than arbor trees in urban areas (heavy traffic areas), whereas arbor trees exert better effects than shrub trees in preventing $PM_{2.5}$ pollution in rural areas.
3. The proportion of shrub trees should be reduced in urban and heavy traffic regions, whereas that of arbor trees should be increased in rural areas.

We studied the effect of each landscape tree species on $PM_{2.5}$ holding capacity and explored reasonable tree species arrangement for the first time. However, this study is limited by tree structure, and typical land use was not considered. These limitations should be overcome in our future studies. Overall, the above results can provide additional useful information for better urban landscape planning and management.

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