Hindawi
Advances in Meteorology
Volume 2022, Article ID 7157012, 10 pages
https://doi.org/10.1155/2022/7157012

Research Article

The Dew Particle Interception Abilities of Typical Plants in Northeast China Plant Leaves Capture Particles in Dew

Yingying Xu, Yingbo Dou, Yan Yi, and Xu Yang

Key Laboratory of Songliao Aquatic Environment, Ministry of Education,Jilin Jianzhu University, No. 5088 Xincheng Road, Changchun 130118, Jilin, China

Correspondence should be addressed to Yingying Xu; xuyingying.1019@aliyun.com

Received 9 February 2022; Revised 21 April 2022; Accepted 25 April 2022; Published 18 August 2022

Academic Editor: Antonio Donateo

The dew condensation frequency is high, and the dew amount is heavy in urban ecosystems. During the condensation process, particulate matter acts as a condensation core, playing an important role in purifying the air. At night, dew mainly condenses on plant leaf surfaces, the plant leaves settle the particles in the dew, and some of the particles are resuspended into the atmosphere in the process of dew evaporation after sunrise. This paper monitored the condensation and evaporation processes of dew on four common plants in Changchun city from June to September 2020. By analyzing the mass and size of particles on different leaves after dew condensation and evaporation, the ability of different plants to retain particles in dew was analyzed. The results showed that there was no significant difference in the TSP capture ability during dew condensation between *Buxus sinica (Rehd. et Wils.) Cheng subsp. sinica var. parvifolia M. Cheng*, *Syringa oblata Lindl.*, *Hemiptelea davidii (Hance) Planch.*, and *Pinus tabuliformis Carrière*, with a TSP content of $0.21 \pm 0.06\,\mu g/cm^2$. Coarse particulate matter is the main type of deposit in the dew condensation stage. Particulate deposition varied according to species, leaf shape, and microstructure. The proportion of TSP remaining on leaves after dew evaporation from *Pinus tabuliformis Carrière*, *Hemiptelea davidii (Hance) Planch.*, *Buxus sinica (Rehd. et Wils.) Cheng subsp. sinica var. parvifolia M. Cheng*, and *Syringa oblata Lindl.* tree was $89.7 \pm 3.9\%$, $80.6 \pm 3.6\%$, $75.9 \pm 4.5\%$, and $71.4 \pm 3.7\%$, respectively. The ability of the leaves to trap fine particles was significantly higher than that for coarse particles ($P < 0.05$) after dew evaporation. The highest amount of particle captured by *Syringa oblata Lindl.* individual was 15.17 g/y during dew condensation, and the amount of remaining particles after dew evaporation was 10.83 g/y. This paper provides a theoretical basis for the selection of tree species for urban greening.

1. Introduction

Atmospheric particulate matter poses a threat to human health, especially to the human respiratory system and immune function [1]. The urban plants are considered to play the role of natural filter in the interception and removal of particulate matter [2]. In Beijing, 772 t of PM_{10} was captured by leaves in one year [3]. The dust retaining capacity of leaves was 8012.89 t/y in Guangzhou [4]. The urban canopy of the Greater London Authority is currently estimated to remove between 852 and 2121 t of PM_{10} annually, representing between 0.7% and 1.4% of PM_{10} from the urban boundary layer [5]. Dew condensation is a common weather phenomenon, and it is also an effective natural atmospheric purification process with the particles in the air serving as a condensation core [6, 7]. Particles in the atmosphere, as condensation cores, experience the process of moisture absorption and homogeneous-heterogeneous phase transition, finally turning to dew. During this condensation stage, particles migrate and settle toward the surface continuously with the condensation of dew, and the dew becomes the sink of near-surface particles ($PM_{2.5}$, PM_{10}, etc.) at night [8, 9]. This leads to the concentration of particulate matter in dew being significantly higher than that in rainwater [10, 11], especially when the concentrations of total dissolved solids (TDS) are high [12]. The average TDS in the dew of Changchun (China) [10] and Delhi (India) [13] can reach 154 and 135 mg/L, respectively.

Due to the large-scale hardening of underlying surfaces and the heat island effect in urban ecosystems, urban areas have become a "landscape unit" with frequent dew condensation, which not only occurs at a high frequency but also in large amount [8, 14]. In Changchun, for example, the annual dew amount in 2017 was 35 mm, and the mass concentrations of TDS, $PM_{2.5}$, and PM_{10} in the dew were 175.31, 24.39, and 49.65 mg/L, respectively. In normal weather, the removal rates of TSP, PM_{10}, and $PM_{2.5}$ by dew were 28.2%, 25.9%, and 21.5%, respectively [15]. The annual removal of particulate matter by dew was 3.11–4.73 kg/ha.

However, atmospheric particulate matter temporarily settles on the leaf surfaces of plants and returns to the air via resuspension [16, 17]. Dew is effective at removing particulate matter from the air near surfaces in urban ecosystems. As an intermediate product forming and dissipating by day and night, the dew evaporates after sunrise, and the particulate matter condensed at night is transferred from the sink to the source during the evaporation process. The $PM_{2.5}$ concentration is highest in the morning but lower in the afternoon and evening in the urban forest of Beijing [18]. Generally, the concentrations of PM_{10} and $PM_{2.5}$ near the surface are minimal from 22 : 00 to 3 : 00 and peak from 7 : 00 to 9 : 00 [18, 19], coinciding with the dew evaporation period [20]. Dew condensation occurs between 20 : 00 and 5 : 00, and the particles can be reduced by wet deposition of dew [21, 22]. The low concentration of particulate matter in the atmosphere at night is closely related to the condensation of dew. However, whether the peak concentration of particulate matter in the atmosphere is related to dew evaporation has not yet been determined.

Because of the hygroscopic behavior of aerosol particles [23, 24], humidity can affect the particle shape and size [25, 26]. The particle size in the atmosphere will change due to aerosol hygroscopicity or volatility whether in the process of dew condensation or evaporation, and it is very complicated and hard to measure. There are some advanced techniques such as ultraviolet aerodynamic particle sizer (UV-APS) fluorescence techniques or fluorescence in situ hybridization (FISH) to measure biological aerosol [27–29]. In this research, the particles deposited on dew condensation and evaporation nodes were observed. The sediment particles and the leaf microstructures were examined by scanning electron microscopy (SEM) in this study. In addition, studies on the interception of particulate matter in plant leaves focus on the interception of dry deposits over time [30]. Some studies identify the source of aerosols by analyzing the chemical composition and backward trajectories [31, 32]. In this study, more attention was paid to the retention capacity of leaves. There is a large and frequent amount of dew water on the leaves of plants in the urban ecosystem, and the concentration of particulate matter is high. Therefore, it is urgent to discuss the amount of particulate matter on leaves in dew deposited at night and evaporated in the morning. The particles monitored in this study are the sediment particles intercepted by leaves. The purpose of this paper is to investigate the capacity of common plants to retain particles of different sizes during the dew condensation and evaporation processes and to discuss the main influencing factors of particles trapped by leaves in dew. The particles measured in this study were naturally captured by leaves, and it will improve the understanding of the ability of dew material captured by different leaves in the urban ecosystems.

2. Materials and Methods

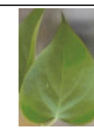
2.1. Experimental Site. Dew and leaf samples were collected at Jilin Jianzhu University, which is located in the southeastern part of Changchun in Jilin Province, China. The continental monsoon climate of the area produces average annual temperatures that vary from −15°C in January to 25°C in August. Precipitation ranges from 522–615 mm/a. The research area is located at the edge of the city, with no industrial and traffic pollution. The dew intensity in summer and autumn is relatively high. For example, in 2014 and 2015, the amount of dew in July, August, and September in the Changchun green area was 46.29 mm and 72.24 mm, respectively, accounting for 22.52% and 23.61% of the precipitation in the same period [15]. Therefore, samples were collected during the peak dew period of summer and fall (June–September) in 2020.

2.2. Plant Selection. Four plants commonly found in northeast China were selected for this study, (*Buxus sinica (Rehd. et Wils.) Cheng subsp. sinica var. parvifolia M. Cheng* (*Buxus*); *Syringa oblata Lindl.* (*Syringa*); *Hemiptelea davidii (Hance) Planch.* (*Hemiptelea*); and *Pinus tabuliformis Carrière* (*Pinus*)). 10–15 plants of each species were randomly selected to actually measure the main characteristics, which are shown in Table 1. To avoid differences in particle interception under different pollution conditions, the selected tree species were all in relatively concentrated areas (see Figure 1).

2.3. Time of Dew Evaporation and Condensation Periods. A tray (diameter of 30 cm) with turf covering both sides was placed on an electronic balance (range of 0.01 to 3000 g). The balance was placed in a waterproof box (with small holes to discharge rain water), and the box was placed on an observation shelf. The observation shelf was equipped with an arm that adjusts in height according to the growth of plants so that the tray and the plant canopy remained at the same height. The weight change of the turf can be continuously monitored, and it is the objective indicator as dew condensation or evaporation. The initial value was recorded half an hour after sunset; when the peak value was reached (approximately half an hour before sunrise), the weight gain value was taken as the dew condensation amount, and the corresponding period was considered the dew condensation period. When the value dropped to a constant weight (the value remained unchanged for half an hour), the dew was considered to have evaporated completely, and the corresponding period was defined as the dew evaporation period.

2.4. Particulate Matter Mass in Dew. Four plant leaves were collected from four directions of the branches at random points in the tree canopy. Thirty to fifty leaves were collected, sealed to avoid vibration, and immediately brought back to

Table 1: Leaf or leaflet traits of the 4 selected plant species.

Species	Height (m)	Leaf size (cm^2)	Texture	Trichomes	Shape	Margin	Number of leaves ($\times 10^4$)	Leaf morphology
Buxus	1.8–3.2	2 ± 0.5	Smooth, waxy	None	Elliptical	Smooth	1.5–2.3	
Syringa	2.5–3.5	51 ± 12.7	Smooth	None	Compound	Lobate	0.9–2.1	
Hemiptelea	2.2–3.1	15 ± 3.8	Rough with multiple veins	Large and few (adaxial); short and numerous (abaxial)	Elliptical	Serrate	2.5–3.5	
Pinus	1.8–3.5	0.4 ± 0.1	Smooth, water repellent	None	Acicular	Smooth	25–28	

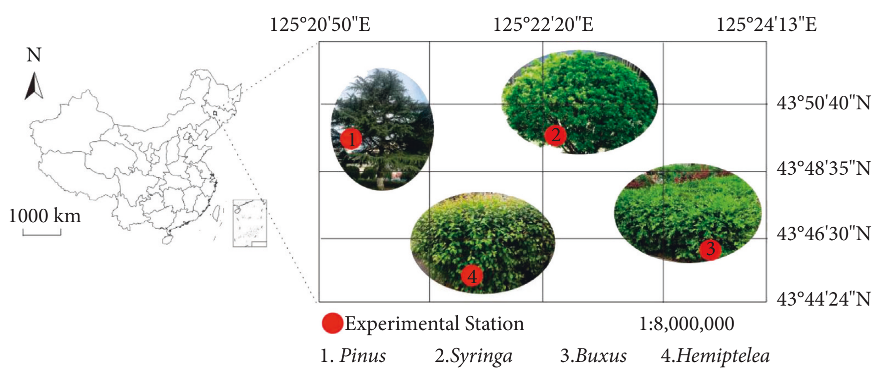


Figure 1: Location of the sample sites.

the laboratory. Cotton balls moistened with alcohol and deionized water were used to thoroughly wash and wipe the surfaces of leaves, to remove dust from the leaves, and to reach an initial state of zero dust accumulation. The leaves were divided into two groups. The leaves in each group were evenly divided into two parts, with half adaxial surface up and half abaxial surface down. The area of leaves (cm^2) was recorded. The leaves were fixed on a polystyrene foam board. The polystyrene board was kept parallel to the surface and was placed at the height of the plant canopy at the beginning of dew condensation.

At the point node when dew condensation turns to evaporation, a piece of foam board was sealed and brought back to the laboratory. The 10.00, 2.50, and 0.22 μm membrane filters were dried (65°C) to constant weight (W_{jf}, g). The surface of the leaves was washed using the ultrasonic cleaner with deionized water for 1 hour, and leaching water was filtered through the filters. The filters were weighed again after dried (65°C), and the weight of filters W_{jc} (g) was recorded. The TSP, $PM_{2.5}$, and PM_{10} values of the dew were calculated based on the weight differences. After the dew evaporated completely, the other foam plate were sealed and brought back to the laboratory. The above steps for weighing leaves (W_e, g) and determining particle residue weight (W_{je}, g) were repeated. All particles were naturally intercepted by leaves, and it was passive sampling.

$PM_{2.5}$/PM_{10}/TSP retention by individual plants during dew condensation and after evaporation was calculated as follows:

$$F_j = \frac{2 \times \left(W_{jc} - W_{jf}\right)}{n} \times N,$$
$$P_j = \frac{2 \times \left(W_{je} - W_{jf}\right)}{n} \times N, \quad (1)$$

where j is the type of $PM_{2.5}$, PM_{10}, or TSP; F_j is the weight of particles during dew condensation for a single plant (mg/plant); W_{jc} is the weight of particulate matter in deionized water (washed off the leaves) when the dew condenses to the evaporation node (g); W_{jf} is the initial weight of the filter paper (g); n is the number of collected leaves on one polystyrene foam; N is the number of leaves on one plant; 2 is the transfer coefficient; P_j is the weight of particles after dew evaporation for a single plant (mg/plant); and W_{je} is the weight of particulate matter in deionized water (washed off the leaves) after dew evaporation (g).

2.5. Particle Diameter Analysis. Particle diameters was measured using a model JL-1166 Laser Particle Analyzer (JL-1166, Chengdu Jingxin Powder Analysis Instrument Co., Ltd., Chengdu, Sichuan, China).

2.6. Meteorological Factor Monitoring. Daily meteorological data, including air temperature (°C), *RH* (%) and wind speed (m/s) at 1 m height, were measured at hourly intervals during the condensation period using a Milos 520 automatic weather station (Vaisala, Finland) at Jilin Jianzhu University.

2.7. Microstructural Analysis of Leaves. The microstructures of the leaves was examined using scanning electron microscopy (SEM). The drop contact angle (DCA) was determined using a Canon EOS550D camera attached to a macrolens (MP-E 65 MM 1 : 2.8) [33]. A 6 μL droplet (for broadleaves) and a 2 μL droplet (for needles) of distilled water were placed on the leaf sample.

Thirty leaves were randomly selected with 3 replicates for each species. Total leaf area was recorded (S). The weighing bottle weight was recorded with a 0.0001 g analytical balance (W_0). Leaf blades were held with tweezers and sprayed with chloroform onto the front or back surfaces for 60 seconds. The extraction solution was then transferred into the weighing bottle. The weighing bottle was weighed on a balance again when the chloroform was completely volatilized in a fume cupboard (W_1). The twice difference ($W_1 - W_0$) of the wax content was measured. The wax content per unit leaf area (W, g/m^2) was determined based on the following formula:

$$W = \frac{W_1 - W_0}{S}. \quad (2)$$

3. Results and Discussion

3.1. Particles Settled by Leaves in the Dew Condensation Stage. As shown in Figure 2, the TSP contents settled by *Pinus*, *Hemiptelea*, *Buxus*, and *Syringa* leaves in the dew condensation stage were 0.21 ± 0.07, 0.21 ± 0.06, 0.22 ± 0.06, and $0.21 \pm 0.06\,\mu$g/cm^2, respectively. There was no significant difference in TSPs per unit area among leaves of each tree.

Coarse particulate matter is the main type of deposit captured by leaves in the dew condensation stage. As shown in Figure 3, the four kinds of trees mainly removed coarse particles (>PM_{10}) in the dew deposition stage. The proportions of $PM_{2.5}$, $PM_{2.5-10}$, and >PM_{10} were 9.2%–16.0%, 26.3%–32.2%, and 56.7%–62.4%%, respectively. As evergreen tree (*Pinus*), the interception of $PM_{2.5}$ proportion was significantly higher compared to other deciduous trees (*Hemiptelea*, *Buxus*, and *Syringa*) ($P < 0.05$), but there was no significant difference in the $PM_{2.5-10}$ and >PM_{10} proportion ($P > 0.05$). It indicated that evergreen plants were better at trapping fine particles. This is similar to the results of other studies. More than 80% of the particles intercepted were PM_{10} of several common green plants in Qingdao [30]. PM larger than 10 μm comprised 73% of PM deposited on leaves in Beijing, with the coarse and fine particle size fractions comprising 16% and 11% of the deposited PM, respectively [22].

3.2. Particles Settled by Leaves after Dew Evaporation. After dew evaporation, the ability of the four kinds of trees to retain particulate matter was obviously different. The proportions of intercepted TSP settled by *Pinus*, *Hemiptelea*, *Buxus*, and *Syringa* leaves were $89.7 \pm 3.9\%$, $80.6 \pm 3.6\%$, $75.9 \pm 4.5\%$, and $71.4 \pm 3.7\%$, respectively (see Figure 4). The ability of *Pinus* (evergreen) to trap particles after dew evaporation was significantly higher compared to several other deciduous tree species. The ability of the four kinds of trees to trap fine particles on their leaves was significantly higher than that for coarse particles ($P < 0.05$). Taking *Syringa* as an example, the leaf interception ratios of PM_{10}, $PM_{2.5-10}$, and $PM_{2.5}$ after dew evaporation were $65.1 \pm 3.9\%$, $83.7 \pm 5.5\%$, and $88.5 \pm 7.3\%$, respectively. After the dew evaporation process, some of the particles were still trapped on the surface of the leaves, and some of them left. The proportion of fine particles trapped in the leaves was higher. After dew evaporation, the particles trapped on the leaves were still mainly coarse particles, but the proportion of $PM_{2.5-10}$ increased to 30.7%–33.7%, and the proportion of $PM_{2.5}$ increased to 11.6%–17.6%. Both the dew condensation and the secondary suspension process were dominated by coarse particles.

There was no significant difference in the mass of particulate matter captured by leaves of different tree species per unit area during dew condensation, but the deposited PM loads varied significantly among individual tree species due to the leaf area (see Table 1). *Syringa* showed the highest PM deposition, followed by *Hemiptelea*, *Pinus*, and *Buxus*. According to the calculation of 130 dew days in one year, the settlement of TSP by one *Syringa*, *Hemiptelea*, *Pinus*, and *Buxus* individual was 15.17 g/y, 12.87 g/y, 2.97 g/y, and 1.07 g/y, respectively, during dew condensation. The remaining TSP trapped by these leaves was 10.83 g/y, 10.35 g/y, 2.67 g/y, and 0.81 g/y, respectively, after dew evaporation. Evergreen or deciduous plants cannot differentiate the intercept of the TSP amount. As the leaves' area increases for each species, the TSP values should be slightly higher than the actual TSP considering the leaves inclination and mutual shadowing with respect to the vertical direction.

3.3. Factors Affecting Leaf Interception of Particles. The relationship between precipitation and particles captured by leaves of the four plants during the dew deposition period was close. The mass of particles on leaves decreased after precipitation (see Figures 2 and 5). For example, the cumulative precipitation reached 53.3 mm from August 13 to 16, and on August 18, the deposition of dew particles in the four plants showed a significant declining trend. This may have been due to purification by precipitation, i.e., the dew captured few particles and resulted in a reduction in

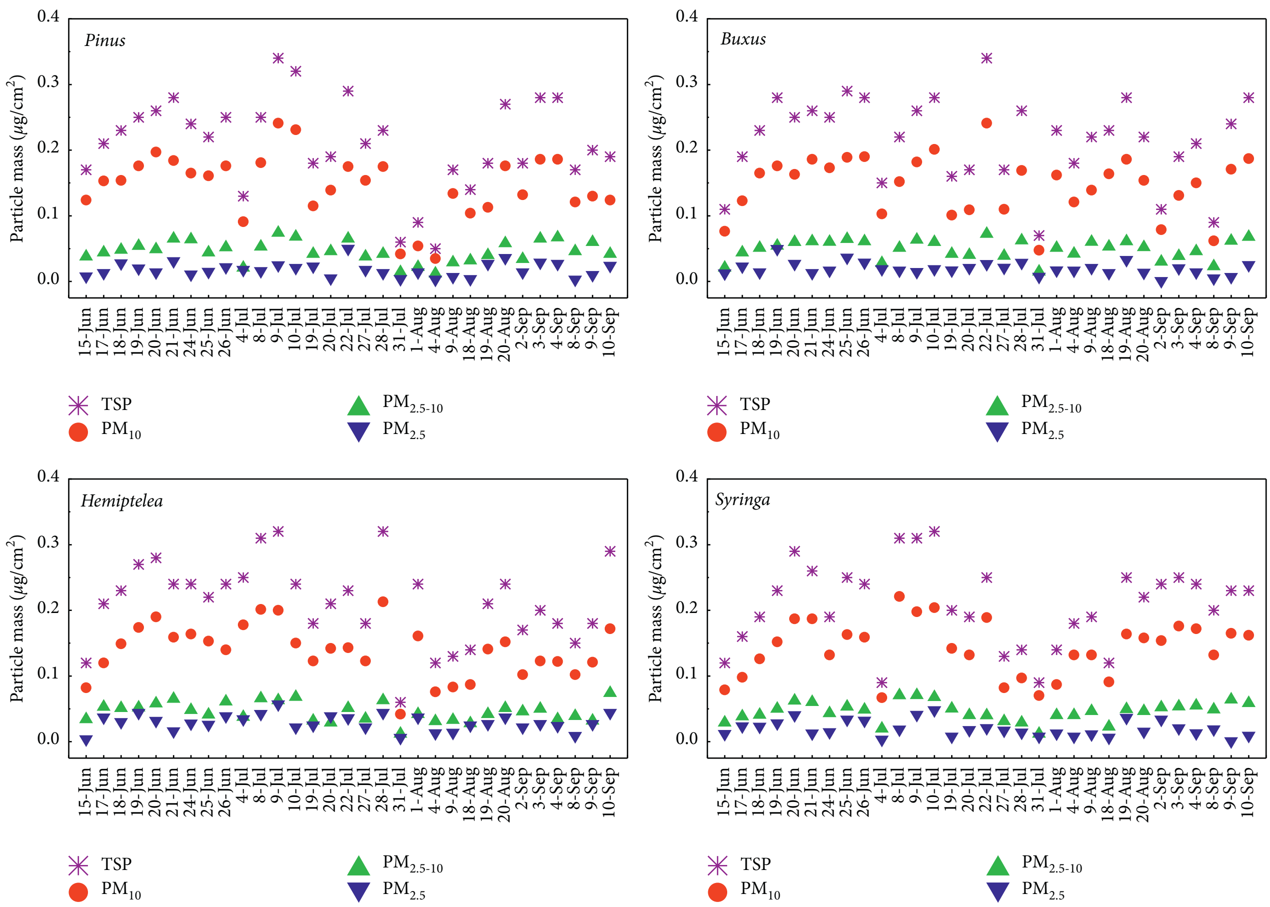


Figure 2: The amount of particles per unit area of different leaves in the dew deposition stage.

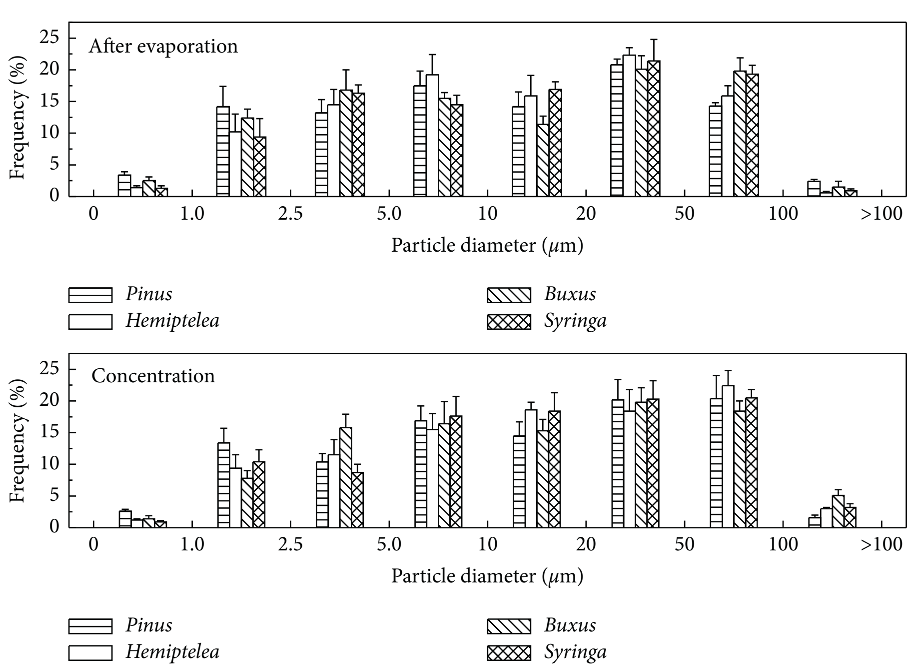


Figure 3: Particle size distribution during dew condensation and after dew evaporation among different plant species.

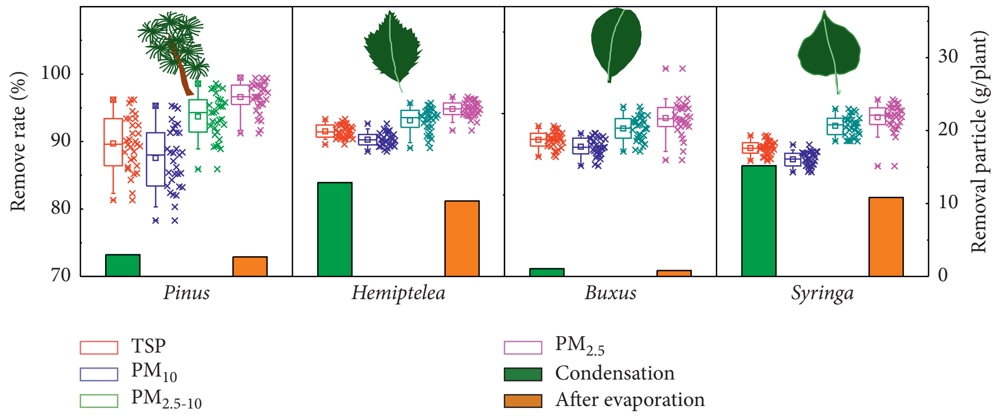


Figure 4: The amount of particles by different leaves and the removal rate of particles of different particle sizes.

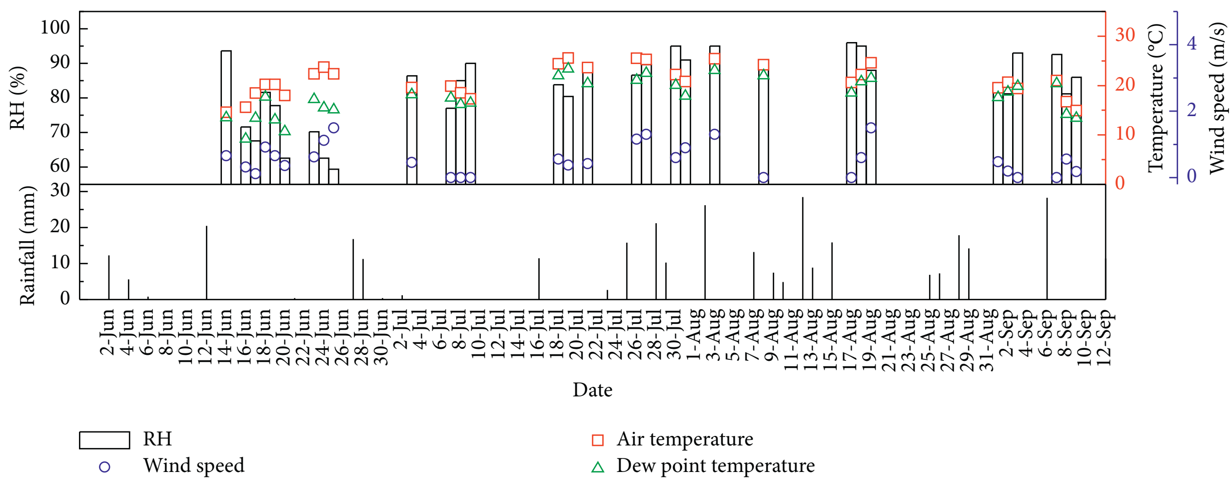


Figure 5: The rainfall from June to September and the meteorological factors during dew evaporation in 2020.

interception [10]. With the increase in pollutants in the atmosphere after rain, samples were taken continuously on August 19 and 20, and the deposition of particles in dew gradually increased.

As demonstrated in Table 2, there was no relationship between wind speed and particulate matter interception amount of four plants ($P > 0.05$). Some researchers found the correlation was positive or negative depending on the local wind speed values, and there was a threshold in the correlation between wind speed and particle concentration [34, 35]. In this study, neither mean wind speed (0.83 m/s) nor 1 m/s wind speed was related to particulate interception ($P > 0.05$). The wind speed had no significant effect on the particulate matter during the dew evaporation period. This is because dew formation events always occur at wind speeds under 2 m/s, and high wind speed conditions are not conducive to dew formation. In addition, the dew evaporation period lasted 3 to 4 hours, and wind has little effect on particulate matter in a short time. The relative humidity during the dew evaporation period was positively correlated with the interception amount ($P < 0.05$) because the particulate matter was not easily dispersed with high air humidity. Air temperature or dew point temperature had no correlation with the interception amount ($P > 0.05$).

Table 2: Correlation coefficients between wind speed and particulate matter interception amount.

	Pinus	*Hemiptelea*	*Buxus*	*Syringa*
Wind speed	−0.183	0.164	0.032	−0.208
>Mean wind speed	0.221	0.343	0.297	0.047
<Mean wind speed	−0.228	0.121	0.038	−0.189
>1.0 m/s wind speed	0.322	0.047	0.243	0.210
<1.0 m/s wind speed	0.175	0.163	0.004	0.153

The four kinds of trees showed little difference in terms of trapping particulate matter in the dew deposition stage, but there were significant differences in their ability to trap particles after the evaporation process (see Figure 4). The ability of plants to capture particle matter is related to multiple factors, including leaf shape and the leaf surface microstructure [36]. According to their leaf morphology, conifers have the strongest ability to trap particles in dew. Conifers exhibited higher $PM_{2.5}$ adsorption amounts than broadleaf trees [37]. The oil secreted by *Pinus* leaves has strong particle adsorption properties (see Figure 6(c)), which also makes it difficult for particles to fall off. The leaves of *Hemiptelea* have serrated edges (see Figure 7(c)), which can also make them more strongly adsorb particles in dew.

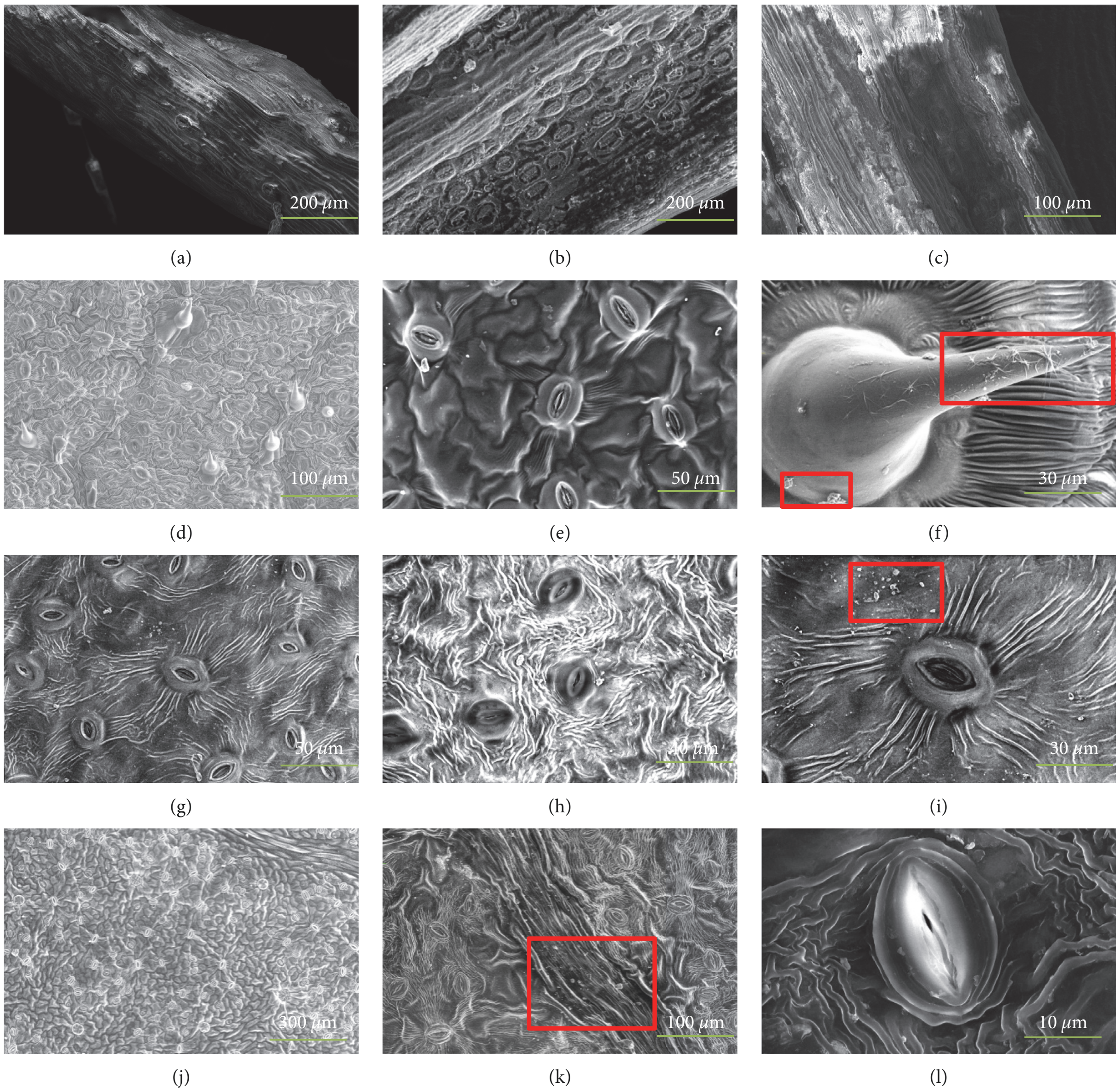
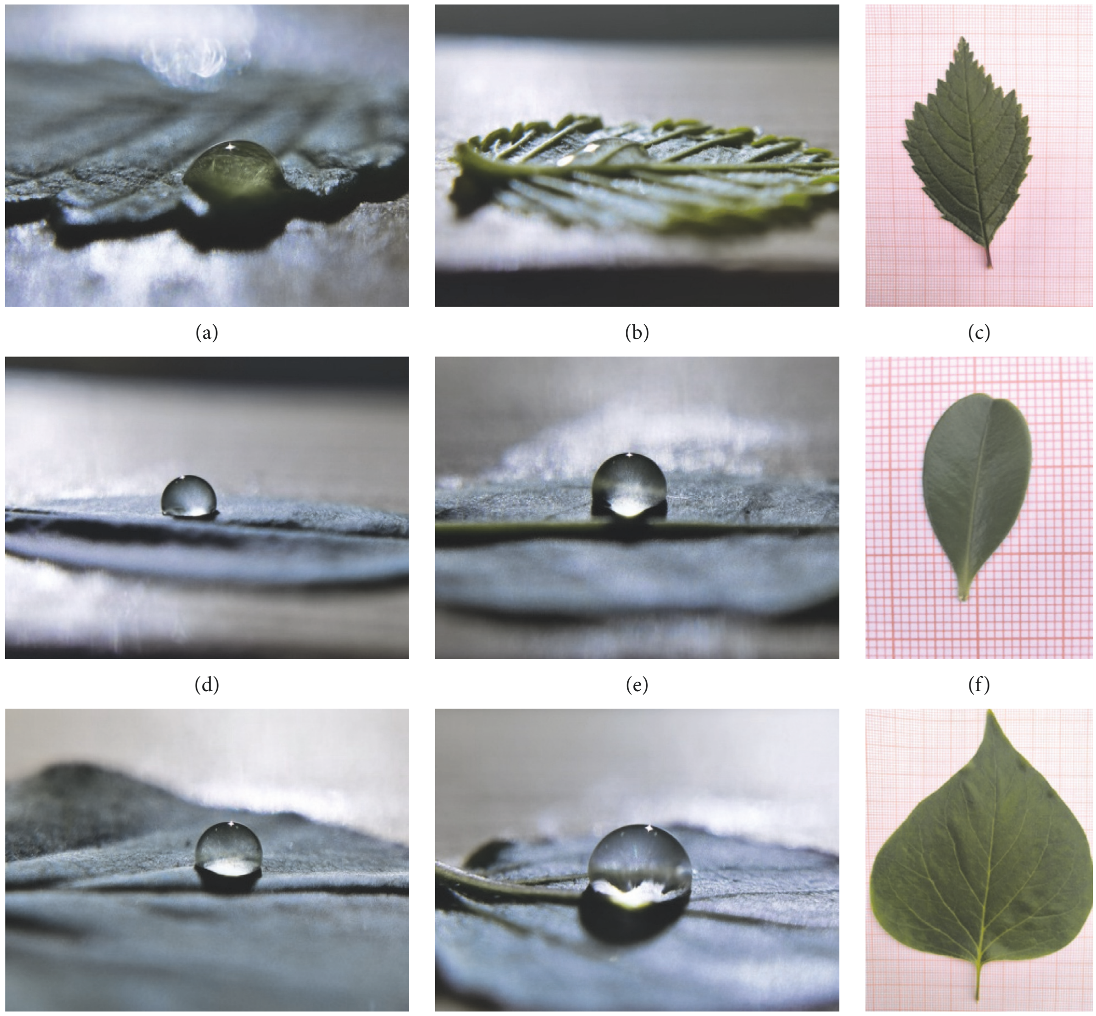


Figure 6: Microstructures of different species with SEM. (a–c) Leaf surface of *Pinus* (×500; ×600; ×1000); (d) adaxial leaf surface of *Hemiptelea* (×1000); (e) stomata of the abaxial leaf surface of *Hemiptelea* (×2000); (f) the base of one of a dense mat of glochid trichomes of *Hemiptelea* (×4000); (g) adaxial leaf surface of *Buxus* (×2000); (h) abaxial leaf surface of *Buxus* (×3000); (i) one stomata of the abaxial leaf surface of *Buxus* (×4000); (j) adaxial leaf surface of *Syringa* (×400); (k) abaxial leaf surface of Syringa (×1000); (l) one stomata of the abaxial leaf surface of *Syringa* (×8000). The structure in the the red rectangle is more inclined to capture particulate matter.

From the aspect of microstructure, the trichome density and length of *Hemiptelea* leaves was significantly higher compared to *Syringa* and *Buxus* leaves (see Figure 6). The trichome surface structures were helpful in enhancing the effective surface area for PM adsorption. Species with trichomes accumulated significantly more particulate matter than other species [38]. Particulate matter adsorption can be observed at the tip and base of the trichomes of *Hemiptelea* (see Figures 6(d), 6(g), and 6(j)). The difference between the removal efficiencies of *T. usneoides* with and without trichome structures was approximately 7% for $PM_{2.5}$ and 2% for PM_{10} [39]. The effect of trichome structure is particularly notable for the adsorption of $PM_{2.5}$. Trichome density has a significantly positive correlation with the maximum particle size ($P < 0.05$), and when the wind force is weak, stomatal density and trichome density have a significant effect on particulate matter resuspension [17]. Therefore, *Hemiptelea* can capture more PM (see Figure 6(f)) than *Syringa* and *Buxus*.

As Figure 6 shows, many fine and coarse particles accumulated on the adaxial leaf surfaces, while some large particles attached to the abaxial leaf surfaces, and few particles became attached in the vicinity of the stomata. Grooves are the main parts of a blade that absorb $PM_{2.5}$.



(a) (b) (c) (d) (e) (f) (g) (h) (i)

Figure 7: Drop contact angle (DCA) and leaf morphology of different species. (a) DCA of the *Hemiptelea* adaxial surface; (b) DCA of the *Hemiptelea* abaxial surface; (c) photograph of the *Hemiptelea* leaf; (d) DCA of the *Buxus* adaxial surface; (e) DCA of the *Buxus* abaxial surface; (f) photograph of the *Buxus* leaf; (g) DCA of the *Syringa* adaxial surface; (h) DCA of the *Syringa* abaxial surface; (i) photograph of the *Syringa* leaf).

Deep grooves can intercept more particles (see Figure 6(k)); additionally, deeper grooves make the release of PM less likely. Ridge ultrastructures at 1-2 μm scale are the most efficient at capturing PM. The stomatal densities of *Syringa*, *Hemiptelea*, and *Buxus* were $213.0 \pm 20.5/\text{mm}^2$, $92.5 \pm 7.3/\text{mm}^2$, and $84.5 \pm 18.6/\text{mm}^2$, respectively. Both stomata and trichomes are adjunct structures that are conducive to the adsorption of particles. Different shapes of leaves captured particles in dew with different ways. Evergreen tree with acicular leaves such as *Pinus* adhered to particulate matter by the secreted oil. While deciduous plants trapped to particulate matter around its unique microstructure, deep grooves or dense trichome such as the elliptical leave (*Hemiptelea*) used dense trichome to trap particulate matter (see Figure 6(f)) and the compound leave (*Syringa*) used deep grooves (see Figure 6(k)).

Otherwise, the content of wax on the surface of *Syringa* (0.79 ± 0.09 g/m^2) was higher than that of *Buxus* (0.38 ± 0.15 g/m^2) and *Hemiptelea* (0.30 ± 0.11 g/m^2), and the DCA of *Syringa* (adaxial surface $143.2^\circ \pm 6.5^\circ$ and abaxial surface $123.4^\circ \pm 10.7^\circ$) was also higher than that of *Buxus* (adaxial surface $107.5^\circ \pm 16.5^\circ$ and abaxial surface $95.3^\circ \pm 12.7^\circ$) and *Hemiptelea* (adaxial surface $80.24^\circ \pm 11.7^\circ$ and abaxial surface $44.2^\circ \pm 7.8^\circ$) (see Figure 7). $10^\circ < \text{DCA} < 90^\circ$ indicates hydrophilic leaves, and $90^\circ < \text{DCA} < 150^\circ$ indicates hydrophobic leaves. *Syringa* leaves have a smoother surface and stronger hydrophobicity than *Buxus* and *Hemiptelea davidii* leaves. Leaves with strong hydrophobicity do not absorb particles easily.

4. Conclusions

Through the monitoring of leaf particle deposition during the dew condensation and evaporation periods of four common urban plants, it was found that the amounts of TSPs settled by *Pinus*, *Hemiptelea*, *Buxus*, and *Syringa* trees in the dew condensation period were 0.21 ± 0.07, 0.21 ± 0.06, 0.22 ± 0.06, and $0.21 \pm 0.06\,\mu$g/cm^2, respectively. There was no significant difference in the TSP amounts in the dew condensation period by leaves per unit area among tree species ($P > 0.05$). Coarse particulate matter ($>PM_{10}$) accounted for 56.7%–62.4% of PM and was the main type of deposit in the dew condensation stage. According to the difference in leaf shape (conifer and broadleaf), microstructure (stomata and trichomes), and hydrophobicity, the proportion of the TSP trapped by *Pinus, Hemiptelea*, *Buxus*, and *Syringa* was $89.7 \pm 3.9\%$, $80.6 \pm 3.6\%$, $75.9 \pm 4.5\%$, and $71.4 \pm 3.7\%$, respectively, after dew evaporation. The fine particle interception ability of leaves accounted for $88.5 \pm 7.3\%$ of the condensed fine particles for the four kinds of trees and was significantly higher than that for coarse particles ($65.1 \pm 3.9\%$) ($P < 0.05$) during the dew evaporation process. Temperature and wind speed had no significant effect on the secondary suspension of particles in the dew evaporation period ($P > 0.05$). More particles were trapped by leaves at higher relative humidity in the morning than at other times. Based on 130 dew days per year, the settlement of TSP by one *Syringa*, *Hemiptelea*, *Pinus*, and *Buxus* individual was 15.17 g/y, 12.87 g/y, 2.97 g/y, and 1.07 g/y, respectively, during dew condensation, and the corresponding values were 10.83 g/y, 10.35 g/y, 2.67 g/y, and 0.81 g/y after dew evaporation. Identifying sources of particles with different particle sizes can help to understand the trajectory of particles and reveal the role of plants in trapping particles. So, the source analysis of particulate matter should be further discussed.

Data Availability

The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

Acknowledgments

This work was supported by the National Nature Science Foundation of China (42175140).

References

[1] G. Q. Tang, P. S. Zhao, Y. H. Wang et al., "Mortality and air pollution in Beijing: the long-term relationship," *Atmospheric Environment*, vol. 150, pp. 238–243, 2017.

[2] A. Przybysz, M. Wińska-Krysiak, M. Małecka-Przybysz et al., "Urban wastelands: on the frontline between air pollution sources and residential areas," *Science of the Total Environment*, vol. 721, Article ID 137695, 2020.

[3] J. Yang, J. McBride, J. Zhou, and Z. Sun, "The urban forest in Beijing and its role in air pollution reduction," *Urban Forestry and Urban Greening*, vol. 3, no. 2, pp. 65–78, 2005.

[4] L. Liu, D. S. Guan, M. R. Peart, G. Wang, H. Zhang, and Z. Li, "The dust retention capacities of urban vegetation-a case study of Guangzhou, South China," *Environmental Science and Pollution Research*, vol. 20, no. 9, pp. 6601–6610, 2013.

[5] M. Tallis, G. Taylor, D. Sinnett, and P. Freer-Smith, "Estimating the removal of atmospheric particulate pollution by the urban tree canopy of London, under current and future environments," *Landscape and Urban Planning*, vol. 103, no. 2, pp. 129–138, 2011.

[6] M. A. Rubio, E. Lissi, N. Herrera, V. Perez, and N. Fuentes, "Phenol and nitrophenols in the air and dew waters of Santiago de Chile," *Chemosphere*, vol. 86, no. 10, pp. 1035–1039, 2012.

[7] D. Beysens, V. Pruvost, and B. Pruvost, "Dew observed on cars as a proxy for quantitative measurements," *Journal of Arid Environments*, vol. 135, pp. 90–95, 2016.

[8] G. Gałek, M. Sobik, M. Błaś, Z. Polkowska, K. Cichala–Kamrowska, and K. Walaszek, "Dew and hoarfrost frequency, formation efficiency and chemistry in Wroclaw, Poland," *Atmospheric Research*, vol. 151, pp. 120–129, 2015.

[9] P. Muskała, M. Sobik, M. Błaś, Z. Polkowska, and A. Bokwa, "Pollutant deposition via dew in urban and rural environment, Cracow, Poland," *Atmospheric Research*, vol. 151, pp. 110–119, 2015.

[10] Y. Y. Xu, H. Zhu, J. Tang, and Y. Lin, "Chemical compositions of dew and scavenging of particles in Changchun, China," *Advances in Meteorology*, vol. 2015, Article ID 104048, 11 pages, 2015.

[11] L. Hong, B. Zhu, X. N. Yu, S. Shi, K. Chen, and L. Xia, "Chemical composition of dew water at a suburban site in Nanjing, China, during the 2016-2017 winter," *Atmospheric Environment*, vol. 211, pp. 226–233, 2019.

[12] M. Muselli, D. Beysens, J. Marcillat, I. Milimouk, T. Nilsson, and A. Louche, "Dew water collector for potable water in Ajaccio (Corsica Island, France)," *Atmospheric Research*, vol. 64, no. 1–4, pp. 297–312, 2002.

[13] S. Yadav and P. Kumar, "Pollutant scavenging in dew water collected from an urban environment and related implications," *Air Quality, Atmosphere & Health*, vol. 7, no. 4, pp. 559–566, 2014.

[14] D. Meunier and D. Beysens, "Dew, fog, drizzle and rain water in Baku (Azerbaijan)," *Atmospheric Research*, vol. 178–179, pp. 65–72, 2016.

[15] Y. Y. Xu and X. Y. Zhu, "Recognizing dew as an indicator and an improver of near-surface air quality," *Advances in Meteorology*, vol. 20179 pages, Article ID 3514743, 2017.

[16] L. Chen, C. Liu, L. Zhang, R. Zou, and Z. Zhang, "Variation in tree species ability to capture and retain airborne fine particulate matter ($PM_{2.5}$)," *Scientific Reports*, vol. 7, no. 1, p. 3206, 2017.

[17] G. Zheng and P. Li, "Resuspension of settled atmospheric particulate matter on plant leaves determined by wind and leaf surface characteristics," *Environmental Science and Pollution Research*, vol. 26, no. 19, pp. 19606–19614, 2019.

[18] T. Nguyen, X. X. Yu, Z. M. Zhang, M. Liu, and X. Liu, "Relationship between types of urban forest and $PM_{2.5}$ capture at three growth stages of leaves," *Journal of Environmental Sciences*, vol. 27, pp. 33–41, 2015.

[19] Y. Gong and X. S. Zhou, "The impact of vehicle exhaust on $PM_{2.5}$ concentration in cities in Northeast China," *IOP Conference Series: Materials Science and Engineering*, vol. 392, no. 4, pp. 042027–42113, 2018.

[20] Z. Y. Gao, W. J. Shi, X. Wang, and Y. K. Wang, "Non-rainfall water contribution to dryland jujube plantation evapotranspiration in the Hilly Loess Region of China," *Journal of Hydrology*, vol. 583, Article ID 124604, 2020.

[21] Z. R. Liu, B. Hu, L. L. Wang, F. Wu, W. Gao, and Y. Wang, "Seasonal and diurnal variation in particulate matter (PM_{10}

and $PM_{2.5}$) at an urban site of Beijing: analyses from a 9-year study," *Environmental Science and Pollution Research*, vol. 22, no. 1, pp. 627–642, 2015.

[22] Y. Y. Xu, Z. Q. Luan, and H. Zhu, "Dew condensation during a typical haze event in Changchun, China," *Journal of Water and Climate Change*, vol. 11, no. 2, pp. 568–576, 2020.

[23] J. Burkhardt, "Hygroscopic particles on leaves: nutrients or desiccants?" *Ecological Monographs*, vol. 80, no. 3, pp. 369–399, 2010.

[24] M. PÓsfai and P. R. Buseck, "Nature and climate effects of individual tropospheric aerosol particles," *Annual Review of Earth and Planetary Sciences*, vol. 38, no. 1, pp. 17–43, 2010.

[25] C. Pöhlker, J. Saturno, M. L. Krüger et al., "Efflorescence upon humidification? X-ray microspectroscopic in situ observation of changes in aerosol microstructure and phase state upon hydration," *Geophysical Research Letters*, vol. 41, no. 10, pp. 3681–3689, 2014.

[26] J. D. Förster, C. Gurk, M. Lamneck et al., "MIMiX: a multipurpose in situ microreactor system for X-ray microspectroscopy to mimic atmospheric aerosol processing," *Atmospheric Measurement Techniques*, vol. 13, no. 7, pp. 3717–3729, 2020.

[27] D. A. Healy, J. A. Huffman, D. J. O'Connor, C. Pohlker, U. Poschl, and J. R. Sodeau, "Ambient measurements of biological aerosol particles near Killarney, Ireland: a comparison between real-time fluorescence and microscopy techniques," *Atmospheric Chemistry and Physics*, vol. 14, no. 15, pp. 8055–8069, 2014.

[28] J. A. Huffman, B. Sinha, R. M. Garland et al., "Size distributions and temporal variations of biological aerosol particles in the Amazon rainforest characterized by microscopy and real-time UV-APS fluorescence techniques during AMAZE-08," *Atmospheric Chemistry and Physics*, vol. 12, no. 24, pp. 11997–12019, 2012.

[29] M. Prass, M. O. Andreae, A. C. de Araùjo et al., "Bioaerosols in the Amazon rain forest: temporal variations and vertical profiles of Eukarya, Bacteria, and Archaea," *Biogeosciences*, vol. 18, no. 17, pp. 4873–4887, 2021.

[30] X. Sun, H. Li, X. Guo, Y. Sun, and S. Li, "Capacity of six shrub species to retain atmospheric particulates with different diameters," *Environmental Science and Pollution Research*, vol. 25, no. 3, pp. 2643–2650, 2018.

[31] L. Wu, X. Li, H. Kim et al., "Single-particle characterization of aerosols collected at a remote site in the Amazonian rainforest and an urban site in Manaus, Brazil," *Atmospheric Chemistry and Physics*, vol. 19, no. 2, pp. 1221–1240, 2019.

[32] S. S. Raj, O. O. Krüger, A. Sharma et al., "Planetary boundary layer height modulates aerosol-water interactions during winter in the megacity of Delhi," *Journal of Geophysical Research: Atmospheres*, vol. 126, Article ID e2021JD035681, 2021.

[33] S. Muhammad, K. Wuyts, G. Nuyts, K. De Wael, and R. Samson, "Characterization of epicuticular wax structures on leaves of urban plant species and its association with leaf wettability," *Urban Forestry and Urban Greening*, vol. 47, Article ID 126557, 2020.

[34] J. H. Wang and S. Ogawa, "Effect of meteorological conditions on $PM_{2.5}$ concentrations in Nagasaki, Japan," *International Journal of Environmental Research and Public Health*, vol. 12, no. 8, pp. 9089–9101, 2015.

[35] Z. Ould-Dada and N. M. Baghini, "Resuspension of small particles from tree surfaces," *Atmospheric Environment*, vol. 35, no. 22, pp. 3799–3809, 2001.

[36] L. Kong, H. Yu, M. Chen, Z. Piao, J. Dang, and Y. Sui, "Effects of particle matters on plant: a review," *Phyton*, vol. 88, no. 4, pp. 367–378, 2019.

[37] S. W. Lu, X. B. Yang, S. N. Li et al., "Effects of plant leaf surface and different pollution levels on $PM_{2.5}$ adsorption capacity," *Urban Forestry and Urban Greening*, vol. 34, pp. 64–70, 2018.

[38] R. J. Leonard, C. McArthur, and D. F. Hochuli, "Particulate matter deposition on roadside plants and the importance of leaf trait combinations," *Urban Forestry and Urban Greening*, vol. 20, pp. 249–253, 2016.

[39] J. J. Kim, J. Park, S. Y. Jung, and S. J. Lee, "Effect of trichome structure of *Tillandsia usneoides* on deposition of particulate matter under flow conditions," *Journal of Hazardous Materials*, vol. 393, Article ID 122401, 2020.