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Dust Capturing Capacity of Woody Plants in Clean Air Zones throughout Taiwan

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Abstract: To exploit the ability of vegetation to capture particulate matter (dust) from the air and improve air quality, 546 clean air zones (CAZs) consisting of various types of urban green space have been established in Taiwan. This study systematically assessed the pollutant filtering efficiency of tree species planted in these green spaces. This research aims to provide quantitative data on individual trees' dust retention functions for future green space planning in urban areas. Field surveys were conducted in 98 CAZs throughout Taiwan. The vegetation composition of approximately 14,000 woody trees, consisting of 210 species, was surveyed. The vegetation surveyed showed that the dominant species in many CAZs in southern Taiwan were introduced species. The dust capturing capacity of the tree species was found to be positively correlated with leaf size. However, the amount of dust retention was affected mainly by the surface structure and morphological characteristics of the leaves, such as a rough, hairy surface. Among the tree species, *Spathodea campanulata*, *Pterocarpus indicus*, and *Delonix regia* exhibited the best dust capture and retention capacity in southern Taiwan, and *Ficus macrocarpa*, *Alstonia scholaris*, and *Melia azedarach* were the most desirable dust retention species. The results suggest that native evergreen species are suitable for dust retention in urban green spaces.

Keywords: air pollutant removal; foliar surface; leaf morphology; dust trapping efficiency; urban green spaces

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1. Introduction

Air pollution, which consists mainly of nitrogen dioxide (NO_2) and dust particles, is now the leading environmental cause of human health problems worldwide. Atmospheric dust particles, also called particulate matter (PM), originate from a broad range of sources that include emissions from the combustion of carbon-based fuels (coal, oil, and natural gas) by industry and vehicles; mineral-containing particles from the erosion of agricultural soils, volcanic eruptions, and building activities; and sea-salt particles from bubbles bursting in oceans and along the coast [1]. Dust particles contain a wide variety of pollutants with various chemical compositions; they affect human health by causing respiratory and heart problems resulting from the inhalation of small particles. Green infrastructure (street and park trees, green roofs, tree belts, and other vegetation introduced into the urban landscape) has recently been promoted by policymakers and scientists for air pollution mitigation, e.g., [2–4].

As with other regions worldwide, Taiwan has severe environmental problems, including air and water pollution. Air pollution is most obvious in Taipei, the capital and largest city. It is in a valley surrounded by mountains, and the primary cause of urban air pollution is the large number of vehicles (mostly motorbikes and scooters) [5]. The clean air zone (CAZ) program is intended to improve air quality, enhance the quality of the living environment, increase awareness of ecological and environmental protection, and achieve sustainable use of natural resources. Within the CAZs, vegetation and beautification are enhanced, and cycling lanes and other greening facilities or landscapes are installed [6].

Between 1995 and 2019, the total greening area grew to 1,764 ha in cities and counties throughout Taiwan [6]. The CAZs include environmental protection parks (202 ha), barren land greening (897 ha), green boulevards (388 ha), cycling lanes (293 km), 180 campus dust improvement sites (205 ha), and pollution sites, landfill reclamation, and greening and restoration parks (277 ha).

CAZs in Taiwan have been established primarily for air quality purification via dust retention. Numerous studies [7–12] have found that plants or forest belts can effectively intercept dust, filter suspended PM in the air, and reduce air pollution. *Acacia confuse* and *Casuarina equisetifolia* presented the highest dust retention capacity in the study of greenbelts in two major highways in Taiwan [10]. Urban forests can significantly contribute to the PM_{10} removal rate [11].

The foliar surfaces of woody plants are exposed to the surrounding environment and are the main receptors of dust. Plants provide a very large leaf area for absorption, interception, and accumulation of air pollutants, reducing the pollution level in the air [13]. Several previous studies [9,14,15] have reported that the dust retention capacity of tree species varies greatly. Dust retention capacity is related to the nature and shape of leaves; leaves with hairy surfaces have a higher dust retention capacity, whereas those with a smooth surface or a large area with a soft texture have low dust retention capacity. An earlier study [15] that used 15 common species in the Taipei area found that *Ficus microcarpa*, *Nageia nagi*, and *Tricyrtis formosana* had the highest dust deposition rates. The type of falling dust also affects the capture efficiency. For example, cement particles are generally more easily retained than soil particles [14,16]. In addition, species composition has an effect on air pollution removal efficiency [17–19]. He et al. [20] found that a 5 m-wide green belt on Sanlihe Road in Beijing filtered and intercepted dust at a dust reduction rate of 85.4%. In addition, the measured dust reduction rate of a 5 m-wide shrub green belt was 22.5%, and the dust reduction rate of a 7 m-wide bush green belt on Beijing Baishiqiao Road was 43.9%.

The dust retention capacity of wet branches is generally greater than that of dry branches [21]. Tsai et al. [22] reported that sprayed branches have the highest dust retention rate for cement particles; they found that dust or cement particles tend to accumulate on the windward side of branches and leaves. The results also show that the dust retention capacity of plants with a small leaf area was higher than that of plants with a larger leaf area. Coniferous trees had more dust than broad-leaved trees [23]; seasonal differences were also observed. Generally, the largest amount of dust is trapped in winter [24], and the chlorophyll content of leaves is inversely proportional to the amount of dust trapped [25].

Since 1995, Taiwan has established 546 CAZs consisting of various types of green space in urban areas; however, the pollutant filtering efficiency of these green spaces has not yet been systematically assessed. The actual tree species composition growing in numerous CAZs is not clear. Some tree species are more pollution-resistant than others. Thus, a thorough field survey is needed to clarify the vegetation composition and explore the dust deposition efficiency of the major tree species in CAZs.

Hence, this study had two research aims. First, it is the first attempt to clarify the dominant tree species and species composition inside the CAZs through field data collection over a wide range throughout Taiwan. The primary purpose is to examine the type of tree species that can be recommended for cultivation in CAZs in terms of dust retention capacity and function of air quality purification. Research on the role of individual trees in urban spaces is still largely lacking [19]. Secondly, this research aims to provide qualitative data on individual trees' dust retention functions for future green space planning in urban areas. This study will also greatly contribute to the knowledge of the dust retention capacity of subtropical and tropical tree species, which are also common in other Asian regions.

2. Survey Sites and Methodology

The main island of Taiwan makes up 99% of the area controlled by the Republic of China (ROC). The ROC, or Taiwan, has an area of 32,260 km^2 and a population of

23.57 million as of August 2020 [26]. There are several peaks above 3500 m, with Yu Shan being the highest at 3952 m, making Taiwan the world's fourth-highest island [27].

Surveys were conducted over two consecutive years, 2010 and 2011. In 2010, 48 CAZs north of Taichung City were selected as sample plots (Figure 1), and 50 CAZs south of Taichung City were selected in 2011 (Figure 1). A full list of selected CAZs is presented in Supplementary Tables S1 and S2. All woody plants with diameters above the root crown or buttress of over 1 cm in the sample CAZs were surveyed. The diameter at breast height (DBH), tree height, and crown width (CW) were measured with a tape measure. However, herbaceous plants were not measured in this study. Field survey data were used to clarify the dominant tree species in CAZs and the contribution of these green spaces to air pollutant removal and carbon storage. Wang et al. [28] reported the vegetation composition of all the surveyed trees and their carbon storage capacity in 2015. They estimated that an overall amount of 672.20 tons of carbon were stored in the sampling plots, and carbon storage benefits are expected to increase as these trees mature.

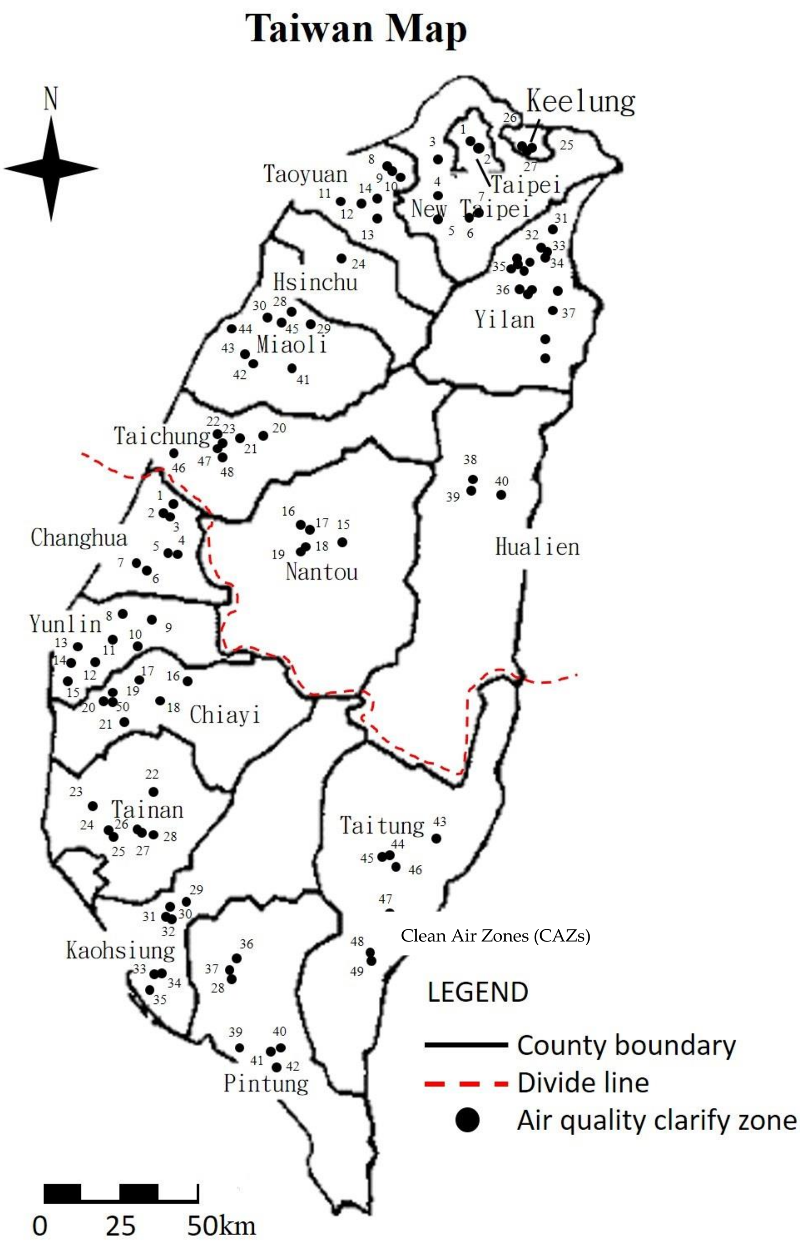

Figure 1. Map of surveyed clean air zones (CAZs).

The data were split into two regions: the southern part and the central and northern parts. We conducted field surveys over two years, taking into consideration the tree number and plot number. In addition, we expected differences in tree species composition in the northern and southern parts of Taiwan due to its large area. However, no significant difference was found between the two regions; hence, we do not include the discussion of tree species structure differences in this study.

2.1. Importance Value Index (IVI)

The importance value index (IVI) of the species was calculated using the method of Curtis and McIntosh [29]. The relative ecological importance of each tree species in each stand was expressed as a summation index (IVI) of the relative frequency (RF), relative density (RD), and relative dominance (RDo) as the following Equation (1):

$$\text{IVI} = (\text{RF} + \text{RD} + \text{RDo})/3 \times 100\% \quad (1)$$

where RF, RD, and RDo are defined as

RF (%) = (frequency of species/total frequency of all species) × 100%
RD (%) = (number of individuals of species/total number of individuals of all species) × 100%
RDo (%) = (basal area of a species/total basal area of all species) × 100%.

The relative frequency is the frequency of a given species divided by the sum of the frequencies of all species. The relative density is the density of a given species divided by the sum of the densities of all species. The relative dominance is the basal area of a given species divided by the sum of the basal areas of all species. The basal area (BA) is defined as the total cross-sectional area of a single tree at breast height and was estimated using the following Equation (2):

$$\text{BA (m}^2) = [\pi \times (\text{DBH(cm)})^2]/10{,}000 \quad (2)$$

where DBH is the diameter at breast height and $\pi = 3.14$.

2.2. Dust Retention Capacity

The dust retention capacity of trees growing in the CAZs was surveyed to screen the tree species, which is desirable for determining their air purification function. Vegetation survey results were used to calculate the IVI of the woody plant species. Ten dominant woody plant species in the two regions were identified.

Dust retention capacity evaluations consisted of two parts: one involved collecting leaves in the sample CAZs, and the other consisted of buying five seedlings of 10 tree species and placing them to be cultivated in the Beishihu Environmental Protection Park, Neihu Reigion (Gong 103) in Taipei City, for experimental use. However, we could not collect all tree species from one CAZ. The surrounding environment and tree growth conditions may have affected the amount of dust accumulated on the leaves. Hence, we selected sample CAZs that had trees with a rich diversity to obtain all the tree species that we needed for the experiments. Relatively better growing trees were selected for tree leaf sampling. Twenty leaves were collected from each tree. The experiments were repeated three times to sample dust four and seven days after rain. In the Beishihu Environmental Protection Park, five seedling tree leaves were sampled six times, four times at four days after rain, and twice at seven days after rain. Only the leaves that looked healthy and in good condition were collected.

In 2009, trees of the same species and similar ages at the New Taipei City Campus were selected for the dust retention capacity experiments. Trees leaves of *Bischofia javanica* were collected from sample CAZ No. 6 (see Supplementary Table S1), and the other nine species were collected from sample CAZs No. 1 and 2 (see Supplementary Table S1).

In 2010, tree leaves were sampled from five CAZs (sample sites No. 2, 5, 6, 7, and 37, see Supplementary Table S2) in the southern part of Taiwan. Tree leaves were sampled 7 days after rain in the southern region, as they were dry in autumn.

The dust load was measured using the formula and methods below (Equation (3)):

$$\text{Actual dust load (gm}^{-2}) = [(W_1 - W_0) \times 10^3]/A \tag{3}$$

where W_0 is the weight of the Petri dish after drying,

W_1 is the weight of the dried Petri dish after the sampled tree leaves were placed in it and washed with deionized water, and A is the area of the sampled leaf measured using the computer scanner method [22]. After scanning, leaf area was determined using a graphical method, which has also been applied in other studies [12,13]. This method calculates the foliar surface area by counting the total number of dots on each scanned image of the leaves. First, a regular or irregular figure was created by scanning a tree leaf. A figure can be defined as an aggregate of numerous dots at a certain resolution. By counting the number of dots in the figure, its area can be determined.

2.3. Sedimentation Velocity of Dust

The speed at which dust particles settle at a constant acceleration in still air is called the sedimentation velocity, defined as the sum of the external forces acting on the dust particles, and is equal to the falling speed of the dust particles at 0 h. The sedimentation velocity can be obtained by dividing the estimated amount of dust by the average atmospheric concentration observed during monitoring.

3. Results

3.1. Vegetation Diversity and Composition

A total of 14,598 trees consisting of 210 species, 145 genera, and 61 families were measured in 98 sample CAZs. There were 681 trees per hectare on average, and this calculation excluded bicycle lanes (Table 1). In terms of relative density (individual numbers), the most common species was *Koelreuteria henryi* (1106), accounting for 7.93%. The top 10 species in terms of the number of individual trees comprised 50.18% of the total number of trees of all species (Table 2). Table 3 lists the tree dimensions measured for the 98 CAZs.

Table 1. Description of areas and number of trees planted in the sample plots.

Sample Clean Air Zones (CAZs) *	Mean	SD	Min	Max
Average area (ha)	0.573	0.728	0.002	4.8
Average species number	11	11	1	75
Average tree number/plot	142	165	5	1181
Average tree number/ha	681	1245	15	7000

* Cycling lanes have been excluded.

Table 2. Tree species with individual numbers exceeding 5% of the total number of trees surveyed.

Species	%
Koelreuteria henryi	7.93
Cinnamomum burmannii	6.56
Terminalia boivinii	6.18
Swietenia macrophylla	5.37
Cinnamomum camphora	5.21
Ficus microcarpa	5.1

Table 3. Tree dimensions of survey plots.

Tree Parameters	Total	North Taiwan	South Taiwan
Mean tree height (TH)	5.76 (1.13–21.00)	5.06 (1.3–14.02)	6.44 (1.38–21.00)
Mean DBH (cm)	15.57 (0.5–190)	11.52 (0.5–53.8)	18.62 (0.6–190)
Crown width (m)	3.95 (0.1–25.5)	3.15 (0.1–16.6)	4.59 (0.20–25.50)
Crown width (m^2)	17.57 (0.01–510.70)	10.33 (0.01–216.42)	23.28 (0.03–510.70)
Mean Basal Area (m^2)	0.03 (0.00–2.84)	0.014 (0.00–0.23)	0.05 (0.00–2.84)

Note: numbers in brackets present the minimum and maximum.

This study surveyed 48 air quality purification zones in 10 counties or cities in central and northern Taiwan. In total, 9,761 trees from 168 species were recorded. The maximum number of trees was 1,715 in Hwalian County, and the minimum was 260 in Taipei City. The overall average tree height was 5.06 m, with an average DBH of 11.52 cm. The total wood volume was 767.05 m^3.

In the 50 sample plots in southern Taiwan, 4837 trees from 140 species were recorded. The cities with the most trees, largest average DBH, largest average CW, and largest average tree volume were Tainan City (933 trees), Kaoshuing City (28.64 cm), and Pingtung County (5.65 m, 0.4056 m^3), respectively.

Table 4 lists the trees with a high IVI in all 98 surveyed CAZs; *F. microcarpa* showed the highest IVI followed by *T. boivinii* and *K. henryi*.

Table 4. Importance Value Index (IVI) of woody plants in the sample plots.

Species	Relative Density	Relative Dominance	Relative Frequency	IVI
Ficus microcarpa	5.1	17.71	12.14	11.65
Terminalia boivinii	6.1	5.58	8	6.59
Koelreuteria henryi	7.79	3.43	8.59	5.6
Cinnamomum camphora	5.21	5.28	6.05	5.51
Cassia fistula	3.79	3.87	7.02	4.89
Alstonia scholaris	2.65	7.9	3.88	4.81
Swietenia macrophylla	5.37	3.5	2.46	3.78
Cinnamomum burmannii	6.56	1.86	2.47	3.63
Pongamia pinnata	3.91	1.06	3.46	3.15
Terminalia catappa	2.45	2.41	4.4	3.09

3.2. Importance Value Index (IVI) in Northern Taiwan

Table 5 lists the 10 species with the highest IVI in the surveyed CAZs in northern Taiwan. *F. microcarpa* showed the highest IVI, followed by *K. henryi* and *C. camphora*.

Table 5. Important Value Index tree species ranking in north of Taiwan.

Ranking	Species	Stem Nos	Basal Area (m^1)	IVI
1	*Ficus microcarpa*	501	46.2	10.13
2	*Koelreuteria henryi*	804	11.3	5.73
3	*Cinnamomum camphora*	534	16.0	5.5
4	*Swietenia macrophylla*	857	12.0	5.15
5	*Terminalia boivinii*	625	12.3	4.99
6	*Cinnamomum burmanii*	891	7.6	4.78
7	*Palimara alstonia*	234	16.0	3.83
8	*Pongamia pinnata*	404	6.6	3.22
9	*Bischofia javanica*	286	6.4	2.96
10	*Prunus sp*	346	1.2	2.43
11	*Melia azedarach*	194	5.7	2.26

Supplementary Table S3 lists the tree species with the highest measured heights among the species with high IVI. In northern Taiwan, *F. microcarpa* had the highest IVI in the surveyed sites in New Taipei City, Keelung City, Yilan County, Taoyuan County, and Miaoli County. *C. camphora* had the highest IVI in Taipei City and Hsinchu City. Additionally, *S. macrophylla*, *A. scholaris*, and *C. burmannii* had the highest IVIs in Huanlien City, Miaoli County, and Nantou County, respectively.

Among the 168 species measured, 43 were included among the 10 species with the highest IVI in a city/county. The tree stem number and tree species number varied widely in the sample plots, as the establishment year was different, and some plots had existing vegetation before the plot was established. Supplementary Table S3 shows that *F. microcarpa* is among the high-IVI tree species in eight cities/counties. *K. henryi* is among the 10 tree species with the highest IVIs in seven cities/counties. *T. boivinii* and *S. macrophylla* are among the 10 tree species with the highest IVIs in six cities/counties. *B. javanica* was among the 10 tree species with the highest IVIs in five cities/counties.

The IVI is the sum of three indices: relative dominance, relative density, and relative frequency. Thus, a tree species with the highest IVI may not have the largest number of stems. However, high-IVI tree species may contribute significantly to carbon storage in its county/city and may be identified as a favorable tree species in the local region. That is, we can assume that six species with high IVIs, *F. microcarpa, C. camphora*, *T. boivinii*, *M. azedarach*, *B. javanica*, and *K. henryi*, were the most popular species in the regions north of Taichung. Among these six high-IVI tree species, five were native and one was exotic.

3.3. Importance Value Index (IVI) in Southern Taiwan

Table 6 lists the 20 species with the highest IVI in the surveyed CAZs in southern Taiwan. *C. fistula* showed the highest IVI, followed by *F. macrocarpa* and *T. catppa*.

Table 6. Important Value Index tree species ranking in the south of Taiwan.

Ranking	Species	Stem Nos	Basal Area (cm^2)	Importance Value Index (IVI) (%)
1	*Cassia fistula*	410	134,685.1	13.36
2	*Ficus microcarpa*	199	281,832.7	8.39
3	*Terminalia catappa*	331	101,833.1	6.47
4	*Terminalia boivinii*	237	121,519.8	5.6
5	*Ficus religiosa*	112	253,623.1	5.47
6	*Palimara alstonia*	136	186,194	4.77
7	*Pterocarpus indicus*	140	118,513.1	4.26
8	*Swietenia macrophylla*	301	87,600.38	4.24
9	*Koelreuteria henryi*	303	43,836.11	3.82
10	*Cinnamomum camphora*	196	73,817.32	3.74
11	*Delonix regia*	90	58,427.5	2.98
12	*Bischofia javanica*	169	53,481.65	2.67
13	*Tabebuia chrysantha*	197	27,223.66	2.46
14	*Pongamia pinnata*	155	25,234.99	2.08
15	*Spathodea campanulata*	87	40,442.15	1.66
16	*Fraxinus formosana*	130	23,672.17	1.62
17	*Senna siamea*	30	55,315.66	1.6
18	*Cinnamomum burmanii*	132	11,150.99	1.33
19	*Ficus elastica*	26	36,396.83	1.17
20	*Podocarpus macrophyllus*	41	49,516.69	1.17

Supplementary Table S4 lists the tree species with the highest IVI in each county/city in southern Taiwan. Among the 140 species measured in the regions south of Taichung City, 30 were among those with the 10 highest IVIs in a city/county. *A. scholaris* had the highest IVI at the surveyed sites in Chiayi and Pingtung. In addition, *C. fistula*, *T. boivinii*, *F. microcarpa*, *F. religiosa, and T. catappa* had the highest IVIs in Changhua, Yunlin, Tainan, Kaohsiung, and Taitung, respectively. Among the 10 tree species with the highest IVIs in the regions south of Taichung City, *T. boivinii* and *C. fistula* had the highest IVI values in six cities/counties. *S. macrophylla* had the highest IVI values among the five cities/counties. These three species are not native, but they were introduced and widely planted, as they are well adapted to the local environment and grow well. *K. henryi* and *C. camphora* were among the 10 tree species with the highest IVIs in five cities/counties. The other six species listed as high-IVI species in three cities/counties were *D. regia*, *B. javanica*, *P. pinnata*, *T. catappa*, *A. scholaris*, and *C. speciosa*.

Of the 30 species among the 10 species with the highest IVIs in the regions south of Taichung City, 18 were exotic and the other 12 were native. Many exotic tree species have been introduced and planted in large numbers inside CAZs. Only a few common native species, specifically *K. henryi*, *C. camphora*, and *F. microcarpa*, were found in the CAZs.

3.4. High Dust Retention Tree Species in Northern Taiwan

The 10 tree species with the highest IVIs (Table 5) were selected based on a survey of 48 plots in northern Taiwan. An *S. macrophylla* seedling was not available; thus, it was replaced by an *M. azedarach* seedling for the experiments described below.

Twenty tree leaves were collected from the 10 selected trees, and the foliar surface area was measured (Table 7 and Supplementary Table S5). The average foliar surface areas of *F. microcarpa* and *T. boivinii* were the smallest (less than 200 cm^2) (Table 7). Tree species with compound leaves had the largest foliar surface area. Among them, *K. henryi* has tripinnately or tetrapinnately compound leaves, and the average foliar surface area was 16,423.9 cm^2. *M. azedarach* has tripinnately compound leaves, but the average foliar surface area was only 5100.00 cm^2. This is very similar to that of *Pongamia pinnata* (5292.4 cm^2), which has pinnately compound leaves. *B. javanica* has ternate compound leaves with an average foliar surface area of 2231.9 cm^2.

Table 7. Average dust load and foliar sizes on the sample CAZs in the north part of Taiwan.

Species	Dust Load (g)	Foliar Size (cm^2)	Dust Load ($mg/cm^2/day$)	Sedimentation Velocity (cm/s)
Ficus microcarpa	0.05 ± 0.04	161.8 ± 69.1	0.29 ± 0.25	5.53 ± 0.13
Prunus sp	0.06 ± 0.04	1043.2 ± 425.6	0.06 ± 0.03	0.77 ± 0.03
Cinnamomum campora	0.02 ± 0.05	273.5 ± 125.8	0.07 ± 0.7	4.12 ± 0.05
Cinnamomum burmanii	0.05 ± 0.06	445.8 ± 217.3	0.10 ±0.11	2.00 ± 0.06
Bischofia javanica	0.09 ± 0.19	2231.9 ± 1021. 0	0.04 ± 0.08	1.25 ± 0.02
Melia azedarach	1.33 ± 0.94	5100.0 ± 2079.2	0.27 ± 0.19	3.57 ± 0.17
Pongamia pinnata	0.19 ± 0.21	5292.4 ± 2295.3	0.04 ± 0.03	0.75 ± 0.02
Alstonia scholaris	0.08 ± 0.06	894.1 ± 593.4	0.10 ± 0.05	1.62 ± 0.03
Terminalia boivinii	0.02 ± 0.05	175.0 ± 75.4	0.12 ± 0.24	3.36 ± 0.07
Koelreuteria henryi	2.54 ± 1.18	16,423.9 ± 8022.7	0.16 ± 0.07	2.46 ± 0.03

The amount of dust on each leaf was positively correlated with the foliar surface area (Table 7). *K. henryi* had the highest average dust load (2.54 g), followed by *M. azedarach* (1.33 g), *P. pinnata* (0.19 g), and *B. javanica* (0.09 g). By contrast, *C. camphora* and *T. boivinii* had an average dust load of 0.02 g, which is attributed to the small foliar surface areas. Regarding the dust capturing amount in terms of every cm^2 of tree leaf area, *F. macrocarpa* ranked the highest, followed by *M. azedarach* and *K. henryi* (see Table 7).

The foliar surface area of the seedlings was relatively smaller than that of the sampled leaves from the CAZs. The dust retention capacity of seedling leaves was similar to that of the samples from the CAZs. *K. henryi* and *M. azedarach* retained the highest amount of dust, measured to be 4.49 g and 3.13 g, respectively (Supplementary Table S5).

Foliar surface characteristics also affected the amount of dust retained. *M. azedarach* and *K. henryi* have rough leaf surfaces, which contribute to their high dust capturing capacity. The average leaf area of *F. microcarpa* was the smallest (161.8 cm^2), which was much smaller than that of *P.* sp. (1043.2 cm^2). However, the two species retained a similar amount of dust (0.05 g and 0.06 g, respectively). The relatively high dust retention capacity was attributed to the waxy foliar surface of *F. microcarpa*. *P. pinnata* and *B. javanica* were ranked the lowest.

The sedimentation velocity of the sampled tree species was determined by dividing the amount of dust retention by the monitoring data of the EPA air quality index. The monitoring data for Neihu District, Taipei City, were available for nine species. Only the samples of *B. javanica* were collected from Butouqiao CAZ, New Taipei City. Thus, the monitoring data of the EPA air quality index in Tamsui District, which is close to New Taipei City, were used for calculation.

The dust sedimentation velocity of the tree species at the sample sites followed the same trend as the dust retention capacity. *F. microcarpa* and *M. azedarach* had the highest dust load capacity and sedimentation velocity. In contrast, the estimated sedimentation velocity of *P. pinnata* was the lowest. The results of the dust sedimentation experiments using seedling leaves were similar to those of the sampled plots. *M. azedarach* had the highest sedimentation velocity, followed by *K. henryi* and *T. boivinii*. In contrast, *B. javanica* and *P. pinnata* had the lowest sedimentation rates.

3.5. High Dust Retention Tree Species in Southern Taiwan

Among the 140 surveyed species in southern Taiwan, 20 had an IVI higher than 1%. *C. fistula* (13.36%) had the highest IVI, followed by *F. microcarpa* (8.39%) and *T. catappa* (6.47%). The others had IVIs of less than 6%. Ten species were selected (Table 6) according to their IVIs, excluding those used in the previous year's experiment in the northern area, and were used for further dust retention experiments.

F. religiosa and *T. catappa* have single leaves. *T. chrysantha* has palmately compound leaves, and *D. regia* has bipinnately compound leaves. The other six species have pinnately compound leaves. The average foliar surface area is presented in Table 8. *C. fistula* and *S. campanulata* had the largest leaf areas of 261.2 and 242.6 cm^2, respectively, because their compound leaves consist of many leaflets. *F. formosana* had the smallest leaf area (25.5 cm^2). *D. regia* had a large leaf area (176.2 cm^2), which was attributed to the large number of leaflets.

Table 8. Average dust load and foliar sizes in sample CAZs the south part of Taiwan.

Species	Dust Load (g)	Foliar Size (cm^2)	Dust Load ($mg/cm^2/day$)	Sedimentation Velocity (cm/s)
Swietenia macropnylla	0.028 ± 0.016	156.4 ± 11.3	0.026 ± 0.014	0.37 ± 0.20
Delonix regia	0.076 ± 0.044	176.2 ± 82.6	0.087 ± 0.061	1.44 ± 1.25
Cassia fistula	0.039 ± 0.010	261.2 ± 10.2	0.021 ± 0.006	0.32 ± 0.08
Tabebuia chrysantha	0.074 ± 0.048	242.6 ± 15.9	0.045 ± 0.031	0.87 ± 0.84
Fraxinus formosana	0.002 ± 0.001	25.5 ± 0.2	0.013 ± 0.006	0.22 ± 0.11
Pterocarpus indicus	0.086 ± 0.075	125.7 ± 11.0	0.100 ± 0.086	1.77 ± 1.80
Ficus religiosa	0.012 ± 0.008	86.0 ± 9.2	0.020 ± 0.015	0.29 ± 0.24
Spathodea campanulata	0.013 ± 0.005	83.9 ± 18.0	0.024 ± 0.013	0.40 ± 0.22
Senna siamea	0.010 ± 0.007	63.4 ± 15.9	0.021 ± 0.015	0.25 ± 0.16
Terminalia catappa	0.022 ± 0.002	92.2 ± 6.8	0.034 ± 0.005	0.52 ± 0.05

The amount of dust retention was almost always positively correlated with foliar surface size (Table 8). *F. formosana* and *S. siamea* had the smallest average leaf size, and their leaves intercepted the least dust. Among the tree species with pinnately compound leaves, *P. indicus* accumulated the most dust, although its average leaf size was not the largest. *C. fistula* had the largest leaf size; however, its dust capturing capacity ranked 7th among the 10 species. The inconsistent relationship between leaf size and dust-capturing capacity may be explained by foliar surface characteristics. For example, *C. fistula* has a glabrous leaf surface, whereas *P. indicus* has a rough surface, which contributes to its greater dust-capturing capacity. *T. chrysantha* also has a rough surface leaf; hence, it was ranked third in terms of its dust capturing capability.

Experiments on seedling leaves also showed that leaf size was positively correlated with dust capturing capacity (Supplementary Table S6). The *S. macrophylla* seedlings had the largest leaves (157.3 cm^2), followed by *T. chrysantha* and *C. fistula*. *F. religiosa* and *F. formosana* were measured to have the smallest leaf size, and they trapped the least dust per leaf on average. The dust capture efficiency ranking is presented in Table 8. The ranking in the seedling experiments was similar to that of the samples from the CAZs.

C. fistula and *F. formosana* have glabrous leaves; hence, their dust-capturing capacity was low. In addition, the blade and petiole of *F. religiosa* leaves were similar in length. Therefore, the leaves swing violently when the wind blows; as a result, the amount of absorbed dust was low. *S. campanulata* has finely pubescent leaflets, and the amount of dust it accumulated was disproportional to the leaf size. Dust collection by newly sprouted leaves among the *T. chrysantha* samples may explain why less dust than expected was captured by the leaves. The data were collected in fall, and *T. chrysantha* is a deciduous species; thus, we were able to collect only young leaves instead of mature leaves.

The foliar surface area of the seedlings was relatively smaller than that of the sampled leaves from CAZs. The dust retention capacity of seedling leaves was similar to that of the samples from the CAZs. *S. macropnlla* and *S. campanulate* retained the highest amount of dust, with values of 0.026 and 0.023 g, respectively (Supplementary Table S6).

4. Discussion

A woody vegetation composition survey in the CAZs revealed that these urban greens/forests accommodate a high diversity of tree species. However, many exotic species have been planted in large numbers inside CAZs, especially in the southern part of Taiwan. In comparison, native species found to be dominant in the CAZs were usually limited to a few species of *F. macrocarpa*, *C. campora*, and *K. henryi*. The exotic species have been widely criticized for their susceptibility to typhoons, and in August 2015, Typhoon Soudelor caused tremendous damage to 16,000 trees in Taipei City, which split or collapsed [30]. Native species are a better choice for greening species, as they exhibit better pest and disease resistance because they are adapted to the climate and environment. Native species are commonly deep-rooted and resilient in regions with frequent typhoons. It is recommended that more native tree species should be cultivated in CAZs to improve biodiversity, as well as forests resilient to the local climate.

It was found that the dust interception and retention capacity of a tree species were related to leaf size and foliar surface characteristics. Furthermore, foliar surface characteristics such as toughness, hairiness, and leaf cuticle characteristics make a greater contribution than leaf size to the dust-capturing capacity of a species. This result is consistent with previous findings that dust accumulation depends on the morphological characteristics of plants [24,31–33]. A long petiole also decreases the dust capturing efficiency, as the leaves swing vigorously when the wind blows. The complex tree leaf structure of pinnately, tripinnately, or tetrapinnately compound leaves also contributes to the dust retention efficiency [34].

Among the dominant tree species in CAZs in northern Taiwan, *K. henryi* and *M. azedarach* had the highest dust capture and retention capacity, which was attributed to the rough foliar surface. *F. microcarpa* was also highly efficient at capturing and retaining dust particles owing to its waxy foliar surface, despite its small leaves. Hence, *K. henryi*, *M. azedarach*, and *F. macrocarpa* are recommended as desirable dust capturing species in the CAZS.

Among the dominant tree species in southern Taiwan, three species, *S. campanulate*, *P. indicus*, and *D. regia*, had high dust retention capacity and can be recommended as the most desirable species in terms of air purification.

Deciduous tree species are not recommended as dust-capturing species. Our study found that *T. boivinii* showed a high dust load capacity; however, we do not recommend it as a dust control species as it is a deciduous species. In addition, *Prunus* sp. is not recommended as a dust control tree species because it is deciduous. Moreover, *B. javanica* and *P. pinnata* are not recommended because of their low sedimentation velocities. The filtering effects of evergreen trees are reportedly better than those of deciduous species [35].

5. Conclusions

CAZs contain a wide range of tree species, including old-growth native species and many newly introduced species. Our survey concluded that trees planted in the CAZs effectively retained some of the PM in the air. As dust control species, we strongly recommend evergreen tree species with high dust capture and retention efficiency. Among the species with high IVI at the survey sites, three species, *K. henryi*, *M. azedarach*, and *F. microcarpa*, are strongly recommended, followed by *A. scholaris*, *C. camphora*, and *C. burmannii*.

In future research, other ecosystem services provided by trees in the CAZs should be assessed, as it has been established that they enhance the quality of life, improve landscape amenity, and protect the environment. Moreover, future research and urban green space planning should also consider the danger caused by trees, such as the emission of biogenic volatile organic compounds (BVOCs) associated with ozone formation [36]. It was found that coniferous and broad-leaved species were predominantly monoterpene and isoprene emitters [37]. Some tree species are the most potent allergen sources and cause a trade-off between the benefits and problems of tree species.

The quantitative data of dust amount captured by individual species can serve as the database for screening the best choice of urban forestry. This database will be expected to contribute to the knowledge of tree species in the tropics and subtropics.

Supplementary Materials: The following are available online at https://www.mdpi.com/article/10.3390/atmos12060696/s1, Table S1 Surveyed Clean Air Zones (CAZs) in north of Taiwan; Table S2 Surveyed Clean Air Zones (CAZs) in south of Taiwan; Table S3 Important Value Index tree species ranking in north of Taiwan; Table S4 Important Value Index tree species ranking in south of Taiwan; Table S5 Average dust load and foliar sizes on the seedlings in the north part of Taiwan; Table S6 Average dust load and foliar sizes of the seedlings in the south part of Taiwan.

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