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Quantification of fine dust deposition on different plant species in a vertical greening system

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Abstract

Urban vegetation has been shown to improve air quality. Green envelopes can provide wide vegetated surfaces in dense cities. This research investigates the performances of four selected plant species used for vertical greening systems, comparing the fine and ultrafine dusts (PM10, PM2.5) collecting capacity by leaves, under the same conditions (height/location, pollution exposition, weather). The ESEM micro- graphs (n = 144) taken on the upper leaf epidermis of 20 leaves show different plant species performances, with *Trachelospermum jasminoides* > *Hedera helix* > *Cistus* 'Jessamy Beauty' > *Phlomis fruticosa*. The 100×, 250×, 500×, 2500× magnifications allow counting a wide range of particle sizes, i.e., from 0.1 to 20 μm. The study demonstrates that some variable investigated, i.e., plant species' shape and surface (thick cuticular waxes on leaf epidermis), influence the amount of particles deposed; while others, i.e., season and age of leaves, do not. This study demonstrates that selecting specific plants in green infrastructure is important to exploit their collecting capacity to increase vertical greening systems performances.

Keywords: Air pollution, PM, green envelope, Counting method, Leaf

Introduction

Air pollution is among the major environmental issue in urban area (European Environment Agency, 2015; WHO, 2013). Traffic- related particulate matter (PM), consisting in fine and ultrafine dusts, nitrogen dioxide (NO2), and ozone (O3), are the major pollutants influencing urban air quality, with daily limits exceeded in several urban regions (European Environment Agency, 2015). These pollutants are limited by European and national policies (Decree 155/2010 implementing the European Union Air Quality Directive 2008/50/EC) and extensively investigated in epidemiological research for their adverse health effects (WHO, 2005). Epidemiological studies demonstrated a strong correlation between increased air pollution, as high levels of outdoor PM, and adverse health effects (Brook et al., 2010; Dominici et al., 2006; Merbitz et al., 2012; WHO, 2013).

According to the European Commission (European Commission, 2015), nature-based solutions, as vertical greening systems (VGS), can be cost-effective solutions providing environmental, social and economic benefits. Studies conducted mainly on urban trees showed the potential effects of vegetation in improving air quality (Janhäll, 2015; Vos et al., 2013; Yin et al., 2011). Bioremediation effects, although not fully investigated yet, are related to fine dust particles deposition and dispersion and to the uptake of gaseous pollutants such as CO2, NO2 and SO2 by plants (Baik et al., 2012; Gromke, 2011; Janhäll, 2015; Thönessen et al., 2008; Vos et al., 2013; Yin et al., 2011).

Ultrafine dust particles (<2.5 µm) are relevant in the dense urban area because they can be inhaled deeply into the respiratory system and cause health problems and affect human beings (Powe and Willis, 2004). Several studies quantified PM interactions with leaf surface or measured PM fluxes captured by trees in urban or periurban areas (Manes et al., 2016; Nowak et al., 2006). Fine dust particles (PM) can be reduced when particles, specifically the smaller size fractions (<10 µm), are adhered to the leaves (Hosker and Lindberg, 1982; Ottelé et al., 2010; Sternberg et al., 2010). The collecting capacity (aerosols/PM) of vegetation depends on several factors as the plants' density, type and configuration (Lin et al., 2016; Tong et al., 2016; Tonneijck and Blom-Zandstra, 2002). These factors affect both deposition – influenced by the Leaf Area Index (LAI, i.e., leaf area/ground area) or the Leaf Area Density (LAD, i.e., leaf area/plant unit volume) – and dispersion (related to porosity) of particles (Janhäll, 2015). Claims in the literature show that, in the case of urban trees, a positive correlation between particle deposition, hairy leaves and wax content of leaves can be found (Sæbø et al., 2012). As shown by Weber et al. (2014) hairy leaves of herbaceous roadside species increased deposition substantially for 3–180 µm particles sizes.

Ottelé et al. (Ottelé et al., 2010) studied the collecting capacity of Hedera helix on leaf epidermis with respect of PM adsorption, concluding that counting particles instead of weighing particles on a specific leaf area seems to be a proper way to classify aerosol deposition on vegetation. Pandey et al. (2016, 2015) shows that climbing plants can be differently tolerant to air pollution, demonstrating that the air pollution tolerance index (APTI), based on ascorbic acid content, leaf extract pH, relative water content and total chlorophyll content, is an important parameter to consider. Also, Rai in a recent review underlines the use of APTI to evaluate the performances of urban vegetation (Rai, 2016).

Aim of the study and research questions

Although several studies previously cited investigated the effects of urban vegetation on air quality, to date, no studies on PM capture ability by vertical greening systems are available. Additional research is needed especially to evaluate the effects of different plant species on particulate matter, since previous researches regarded only Hedera helix (Ottelé et al., 2010; Sternberg et al., 2010).

Differently from the other greening strategies for urban areas, vertical greening systems, as the one investigated in the present research (Fig. 1), can be based on living wall modules, a mat planted with different species, combined with climbing plants attached to a steel mesh. This plant arrangement, together with an accurate species selection, provides a potentially different barrier to PM deposition and gaseous air pollutant absorption compared to trees and shrubs used for other urban greening solutions (Thönessen et al., 2008).

The present study analyses four different species, climbers and shrubs, planted on a vertical greening system located in a dense urban area (in Genoa city centre, Italy), comparing fine and ultra- fine dusts (PM10, PM2.5) deposition under the same conditions (height/location, pollution exposition, weather). The influence of season and age of plants on particle deposition is evaluated, analysing samples collected in different seasons. Finally, the possible influence of rain on particle adherence is further investigated, by reason of the different conclusions drafted by previous studies (Ottelé et al., 2010; Popek et al., 2013; Przybysz et al., 2014). Therefore, the following research questions can be drafted:

Is there any difference between the plant species analyzed, due to different leaf shape and epidermis, in collecting fine and ultrafine dusts (amount and size of particles)?

Is there any difference between the time of deposition (3 and 6 months after planting, summer and fall respectively)?

Can particles be washed away by rainwater from leaves with different leaf shape and epidermis?

The present research allows evaluating the influence of several factors, as the plant species and structure (leaf shape, epidermis, roughness, etc.), sampling season and timing, sampling location, on the amount and size of particles collected, and it provides the data needed for a comprehensive study of the effects of vertical greening system on air quality.

The present study is part of a wide research project focused on the monitoring of the National Institute of Social Insurance (INPS) Green Facade pilot project, which includes the analysis of environmental, economic and social benefits in the context of densely urbanized areas, especially those in the Mediterranean region (http://www.ecosystemics.eu/?page id=474) (Magliocco and Perini, 2015; Magliocco et al., 2015).

Methodology

The study is focused on counting fine and ultrafine dust particles on Environmental Scanning Electron Microscope (ESEM) micrographs. Since the aim of the study is to compare different plant species performances under the same conditions (height, pollution exposition, weather), four plant species were chosen among the ones used for the INPS Green Facade. The National Institute of Social Insurance (INPS) Green Facade, the first built in Genoa (Italy), was installed on the south facade of a public institution office building, renovated in the ‘80 s (Fig. 1). The building is located in the city centre of Genoa Sestri Ponente. The district is characterized by a relatively high population density (13,000 inhabitants/km2) and road traffic which causes severe air pollution. In Genoa city centre air quality monitoring results (http://www.banchedati.ambienteinliguria.it/) show high levels of particulate matter. In 2015, for example, the Regional Environ- mental Protection Agency’s monitoring systems registered values exceeding yearly values (40 µg m−3 according to D.Lgs. 155/2010, Repubblica Italiana, 2010) for 1486 h (i.e., about 60 days; average PM10 = 35.09 µg m−3, n = 293 and average PM2.5 = 21.76 µg m−3, n = 267 in the most polluted station).

Evergreen plant species, with different types of leaf shape and epidermis (roughness), were selected (Table 1). Other parameters for the plants’ selection include health, adaptation capacity and foliage density.

The plant species analysed in this study are:

- *Cistus* ‘Jessamy Beauty’ (Cistaceae), an ornamental hybrid of a perennial evergreen shrub native of Mediterranean Region (Perini et al., 2016).
- *Hedera helix* (Araceae), a woody climber native to western, cen- tral and southern Europe, with high adaptation capacities in several climate areas. It has both juvenile and mature leaves. The growing speed is medium (0.5 m/year) (Bellomo, 2003).
- *Phlomis fruticosa* (Lamiaceae), an evergreen large and broad shrub native of Mediterranean Region, growing about 1 m tall and wide, with grey-green ovate leaves up to 12 cm in length with hairs (Poletti, 2015).
- *Trachelospermum jasminoides* (Apocynaceae), a vigorous medium-sized evergreen twining woody climber growing up to 4–8 m high (“RHS Home Page/RHS Gardening,” n.d.).

Sampling and data analysis

The experiment includes two sampling periods (July and October 2015) at the study site, INPS Green Facade. For each of the four plant species analysed, 2 leaves were randomly chosen from the same height, i.e., 5 2 m, to allow the sampling through the windows at a reasonable distance from traffic ± source (i.e., 2–3 m; Fig. 2). In both cases (July and October) no raining was recorded within the 15 days before sampling, with average rainfall of 4.4 mm for May, June, and July and 4.3 mm for August, September, and October. For the latter the average wind speed recorded is 2.8 m s−1, while for the first trimester is 1.8 m s−1. Since the species were all planted on the INPS Green Facade in March 2015, the first sampling was done 3 months after planting and the second 6 months after.

To exclude the possibility of contamination after sampling, leaves were sealed in a labelled plastic container.

All the leaves were analysed within one week after sampling at the Microlab of Delft University of Technology with ESEM microscope. To investigate the elemental composition of the particles on the leaves the Energy Dispersive X-ray Spectrometry-analysis (EDS-analysis) or elemental-mapping technique was done on a Philips XL30 ESEM with a tungsten filament. The Energy Dispersive X-ray analysis (EDX) system is by EDAX with a super ultra-thin window (version 3.3) and a resolution of 128.0 eV. The lower detection limits are 0.01 wt.% for all element species.

In total 4 positions per leaf (upper leaf epidermis (Ottelé et al., 2010)) were analysed with ESEM (Fig. 3), while for chemical (elemental) analysis 1 or 2 random positions per leaf were chosen. The micrographs are taken with different magnifications: 100×, 250×, 500 and 2500 . To conduct the elemental analysis, 20 particles per leaf were analysed for both sampling (July and October).

To deeply analyse the possible particle loss during rain events, and to confirm or reject what was previously demonstrated (Ottelé et al., 2010; Popek et al., 2013; Przybysz et al., 2014), two leaves of *H. helix* and *P. fruticosa* were washed with water to simulate rain.

In the presented study, the counting method (Ottelé et al., 2010) was used.

Data processing and statistical approach

In total 144 micrographs (100, 250, 500 magnifications) where taken with the electron microscope on randomly chosen spots (2 sampling, 4 plant species, 4 positions per leaf, 3 magnifications). In addition, 16 micrographs with 2500 magnification, 4 per plant species, and 32 magnification (100 and 500) on washed leaves of *H. helix* and *P. fruticosa* were taken.

The software Image J (http://imagej.nih.gov/ij/) was used to count the particles found on each magnification (100 , 250 ,500). Image J allows creating binary images (i.e., black and white) and distinguish particles from the leaf epidermis (background), with the function threshold. Once particles overlapping are separated, thanks to the function watershed, size and number are analysed, without boundary to the circularity. Image J counts particles and the related area. In this experiment particle diameter was calculated afterwards.

To provide an overview on the amount of deposited particles on the leaves analysed, the magnifications are used to count the following particle sizes: 100× for particles > 10 µm, 250× for particles 2.5–10 µm, 500 for <2.5 µm. Weighting factors were used to compensate the loss of counting area due to zoom for 250 and 500 . For all the cases analysed a surface of 1 mm2 was considered to compare amount and size of particles. Considering all the particles counted on each magnification (100%), the amount of particles of different size were counted, e.g., >20 µm or <2.5 µm.

The 2500 magnification was used only for qualitative comparison, since such a small area of a leaf cannot provide reliable results for quantification.

Considering the high number of samples analysed, the left- skewness of the distribution of data, and all the variables considered, a Welch’s t-test was performed to check whether different plant species studied collect a similar amount of particles (i.e., the null hypothesis), according to the formula:

$$t=(m_A-m_B)/\sqrt{\frac{s_A{}^2}{N_A}+\frac{s_B{}^2}{N_B}}$$

where NA (NB), mA (mB) and sA2 (sB2) are the sample size, the sample mean and the sample variance respectively.

Results and discussion

Counting particles

The experiment allows comparing the performances of four different plant species in terms of collecting capacity, i.e., the sink capacity of vegetation depending on leaves macro- and micromorphology. As shown in Figs. 3 and 4 and as briefly described in the Section 2. Methodology, the plant species' leaves have different shapes and epidermis roughness, i.e., trichomes, cuticular waxes, etc.

The normalized density charts (Figs. 5 and 6) show the average number of particles in 1 mm2 area for all the plant species ana- lysed. This first overview shows the different plant species ability in collecting fine and ultrafine dusts, highlighting a different collecting ability among the plant species, where *T. jasminoides* collects a higher number of particles. Looking at the particle size distribution, particles 10 μm appeared to be rather rare compared to particles 10 μm (as found Ottelé et al., 2010). The highest number of particles is found in the range 0.5–2.5 μm (PM 2.5), with a peak from 0.5–1 μm. The same trend is noticed for both sampling periods. The slight difference of particles amount, although not statistically significant (Table 2) can be related to the age of the leaves (i.e., longer time of deposition, development of thicker cuticular waxes, or changes in waxes structure under atmospheric pollutants stress Rai, 2016), and not only to the sampling season.

Considering specifically the 100 x magnifications, the particle counting (Figs. 7 and 8) shows higher concentrations of smaller particles (2.5–3.75 μm). Figs. 7 and 8, i.e., the percentage distribution of particles per mm2 according to their size, also show that almost no difference among the plant species can be found, with an extreme data concentration. A slight peak of 10–15 μm particles can be noticed. The different trend compared to Figs. 5 and 6, i.e., the average number and size of particles based on 100×, 250×, 500 magnifications, can be related to the magnification used (Figs. 7 and 8 are based on 100), which focuses on 2.5–20 μm.

Focusing again on the number and size of particles in 1 mm2, the 500 magnification (Fig. 9) highlights the difference between *P. fruticosa* and *T. jasminoides*. These two plant species have very different shape, leaf shape and micromorphology, which probably influence their collecting capacity in terms of amount of particles. The results of this study show a positive relation between less rough but waxy leaves and particle deposition (as found in the case of trees; Sæbø et al., 2012). Differently hairy leaves negatively influence the plant's performances, showing a different behaviour compared to urban trees (Sæbø et al., 2012) and to herbaceous roadside species, as shown by Weber et al. (2014).

The analysis of the samples shows that percentage values do not provide statistically relevant differences between the distribution of particle size in each sample (Figs. 7 and 8), while a different trend can be noticed for the density values (i.e., total amount of particles in 1 mm2, Figs. 5 and 6), with an average 30% decrease, from October to July, and with the peaks 35% for *H. helix* (HH), *Cistus* 'Jessamy Beauty' (CJ) and *P. fruticosa* (PF), and 75% for *T. jasminoides* (TJ).

As shown in Table 3, for both sampling periods, the null hypothesis (i.e., the leaves have a similar fine and ultrafine dust density), can be rejected (high reliability of data), with TJ > (CJ and HH) > PF. These differences can be related to the specific characteristics of the leaves, i.e., their thick cuticle and waxes, as in the case of *T. jasminoides*. As also stated by Popek (Popek et al., 2013), cuticular waxes of leaf epidermis is among the main parameters which influences collecting capacities probably thanks to its hydrophobic nature that represents the limiting barrier for foliar uptake of water-soluble compounds (Sawidis et al., 2011).

In order to demonstrate if the particles can be washed away by rainwater, 32 samples of washed and non washed leaves of *H. helix* and *P. fruticosa* are analysed with 100 magnifications. The results of particle counting of washed and non-washed *P. fruticosa* and *H. helix* leaves show that particles (2.5–10) cannot be washed away by rainwater, since the average number of particles in 1 mm2 is similar (Fig. 10). This confirms Ottelè et al. (Ottelé et al., 2010) results, who demonstrate that fine and ultrafine particles cannot be washed away from H. helix leaves. Also according to Terzaghi et al. (Terzaghi et al., 2013) only particles smaller than 10 μm can be encapsulated into the leaf cuticle, i.e., could not be washed away by rainwater. According to Przybysz et al. (2014), particles, mainly the coarser fraction, are washed off from foliage during rain. This effect is reduced by the presence of wax on leaves (Dzierzanowski et al., 2011). Popek et al. (Popek et al., 2013) show that approximately 60% of the particle deposit was washed off with water, while 40% was included in the wax layer, with a large variance between species. Our findings agree with Sternberg et al. (Sternberg et al., 2010) who show that ivy acts as a 'particle sink', absorbing particulate matter, particularly in high-traffic areas with high level of fine (2.5 μm) and ultrafine (1 μm) particles. This could probably be related to the thick leaf epidermis, specifically high level of waxes and leaf micromorphology alterations (Rai, 2016).

Fig. 11 shows some 2500 magnifications for the species analysed. Since the area of analysis is too small and magnifications can be very different (areas with no particles or area full of particles), 2500 magnifications are analysed only to show possible ultramicroscopic differences between the species. This difference cannot be found. 2500 magnifications demonstrate the presence of very small particles on the leaves, i.e., <0.1 μm.

Elemental analysis of PM deposition

Table 4 summarises the results of the elemental analysis. The most abundant elements found on the leaves were Fe, Si, and Ca in relation with resuspension of urban road dusts (Wang et al., 2006). The most notable differences among the two sampling periods regard Cr, found on 2 particles belonging to the October sampling, and Cl and Na, which was identified in less particles for October sampling but with higher weight. The presence of Cr particles can be related to car traffic and to the presence of a railroad near by the facade (200 m far). Fe and Si can be both mineral dusts and soil components. The proximity of INPS Green Facade to the seaside can explain the high levels of Na. The C content derives from the leaf epidermis (Ottelé et al., 2010).

Further analysis can be done to deepen elemental analysis and its relations with leaf epidermis structure (cuticular waxes, trichomes, leaf thickness under PM pollution, etc.) and physiology (photosynthetic performance).

Conclusions

The present study is focused on counting fine dust particles on four plant species of a vertical greening system installed in Genoa (Italy). The main conclusions that can be drawn from the presented results are the follows:

there are great differences on particle deposition among *Cistus* 'Jessamy Beauty', *H. helix, P. fruticosa*, and *T. jasminoides*, showing the influence of plant species and structure (leaf shape, epider- mis, roughness, etc.) on the total amount (number) of particles collected. Waxy leaves (*T. jasminoides*) collect the highest significant amount of particles from the atmosphere. Hairy leaves (*P. fruticosa*) are less effective and thus not a suitable option for improving air quality. With respect to this last conclusion, worth mentioning that different results were found by other studies (e.g., Janhäll, 2015; Sæbø et al., 2012), therefore this aspect should be further investigated (e.g., with the analysis of different plant species with hairy leaves).

not significant differences were found between the two sampling periods, summer, 3 months after planting and fall, 6 months after planting. Therefore, this study shows that sampling season and timing has no influence on the results.

particle sizes between 2.5 and 10 µm cannot be washed away from both waxy (*H. helix*) and hairy (*P. fruticosa*) leaves.

This experiment demonstrates that the effects of vertical greening systems on particulate matter concentration depends on the specific characteristics of plant species. All the species analysed are evergreen, thus provide similar benefits in terms of air quality improvement during the different seasons (Sæbø et al., 2012). However, other parameters to consider for the plant species choice include health, adaptation capacity and foliage density. Starting from the results of the study presented, it will be possible to further investigate the ability of plant species in terms of collecting capacity, based on the plant's shape and surface (Leaf Area Index and Leaf Area

Density). This study demonstrated that the selection of specific plant species highly influences the performances of vertical greening systems affecting the PM resuspension in the air.

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Further reading

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FIGURES

Figure 1

Fig. 1. INPS Green Façade pilot project, Genoa (Italy). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

Figure 2

Fig. 2. Green fac¸ ade sampling positions (red points). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

Figure 3

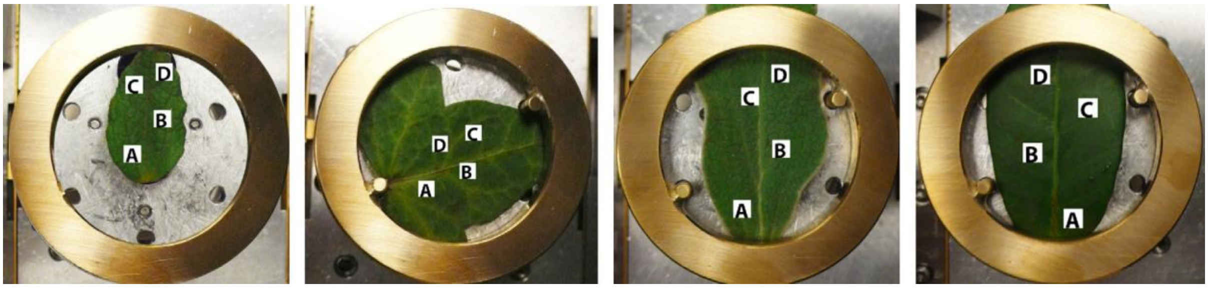


Fig. 3. Leaves Cistus ‘Jessamy Beauty’, H. helix (juvenile leaf), P. fruticosa, *T. jasminoides* in ESEM microscope with the analysed random leaf positions (A, B, C, D).

Figure 4

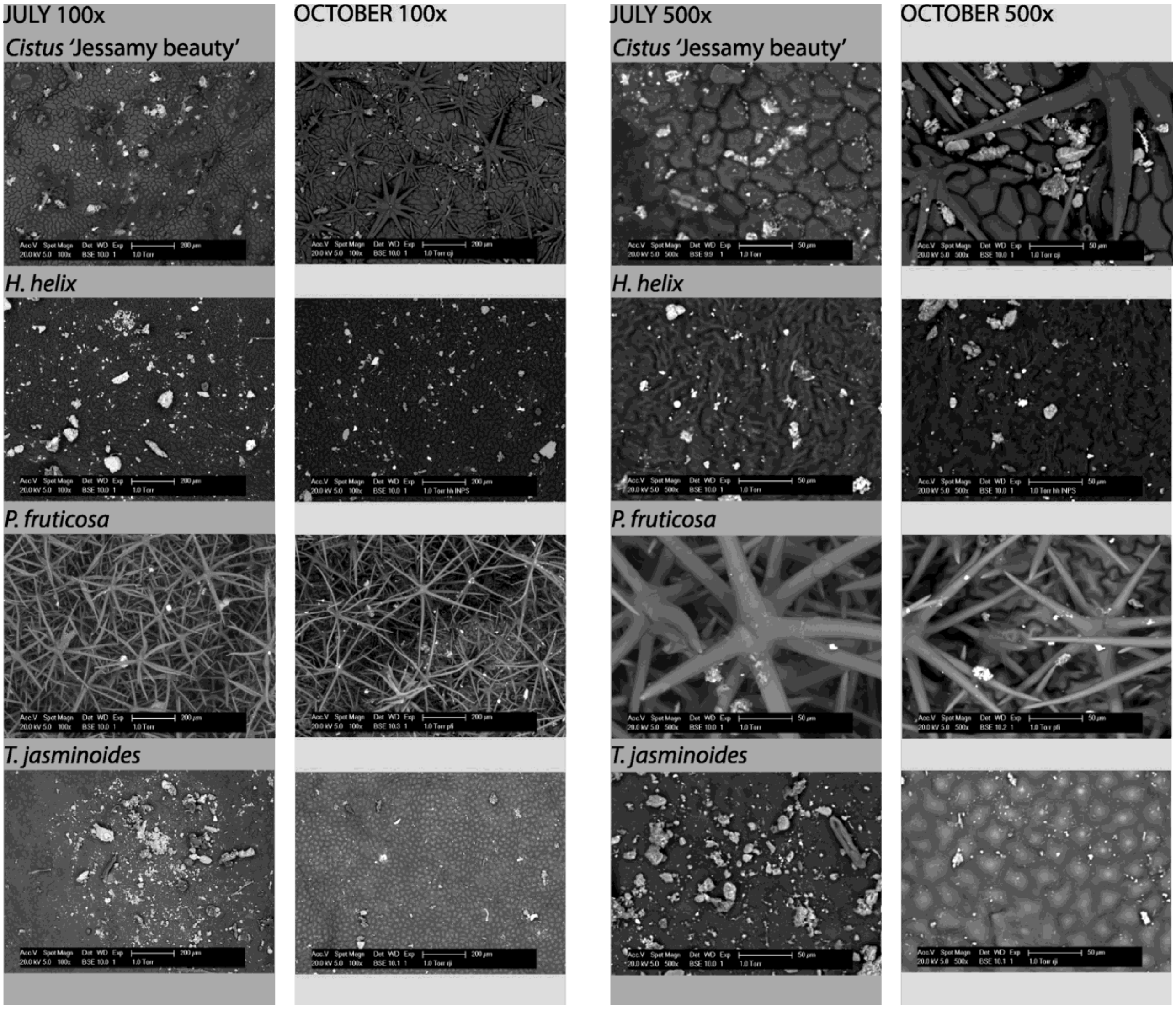


Fig. 4. Comparison scheme for the species analysed H. helix, Cistus 'Jessamy Beauty', P. fruticosa, *T. jasminoides*, 100× and 500× magnification, July and October sampling.

Figure 5

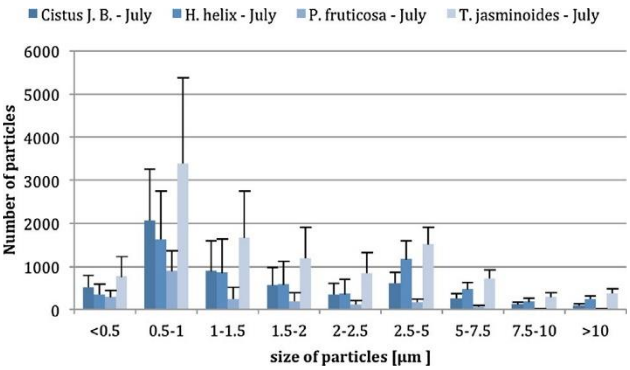


Fig. 5. Normalized density charts, average number and size (μm) of particles in 1 mm2 for *H. helix*, *Cistus* 'Jessamy Beauty', *P. fruticosa*, *T. jasminoides*, based on 100×, 250×, 500× magnifications, July sampling (n = 96, data are mean ± SD).

Figure 6

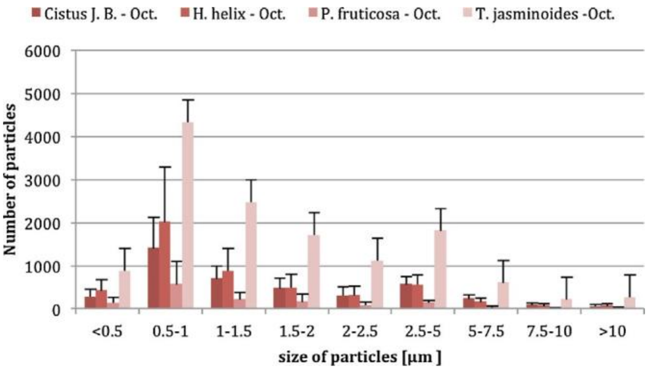


Fig. 6. Normalized density charts, average number and size (μm) of particles in 1 mm2 for *H. helix, Cistus 'Jessamy Beauty'*, *P. fruticosa*, *T. jasminoides*, based on 100×, 250×, 500× magnifications, October sampling (n = 96, data are mean ± SD).

Figure 7

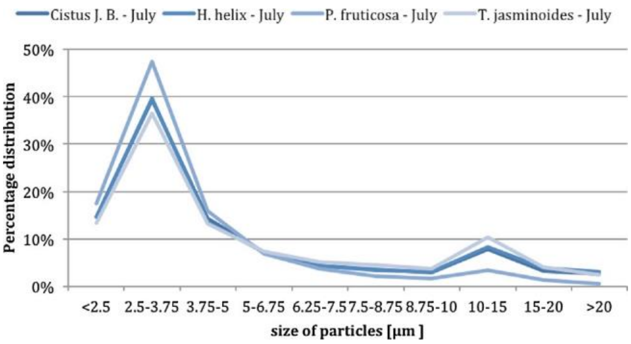


Fig. 7. Percentage distribution of particles per size (μm) in 1 mm2 for *H. helix*, *Cistus* 'Jessamy Beauty', *P. fruticosa*, *T. jasminoides*, based on 100× magnification, July sampling (n = 32).

Figure 8

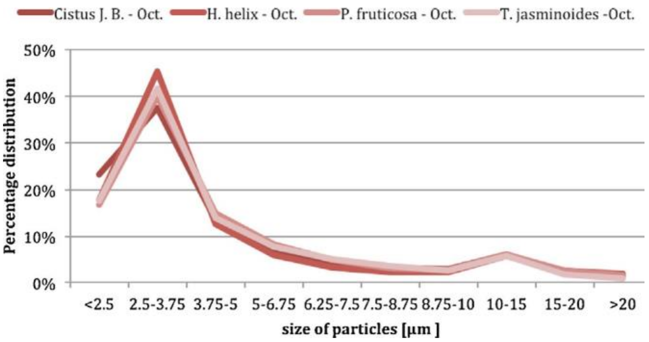


Fig. 8. Percentage distribution of particles per size (µm) in 1 mm2 for *H. helix*, *Cistus* 'Jessamy Beauty', *P. fruticosa, T. jasminoides,* based on 100× magnification, October sampling (n = 32).

Figure 9

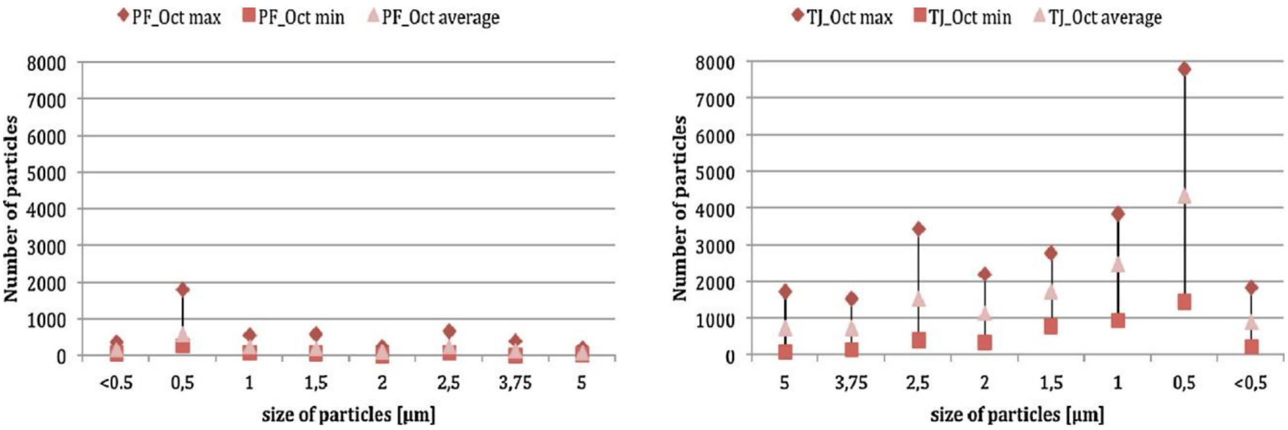


Fig. 9. Number and size (µm) of particles in 1 mm2 for *P. fruticosa* based on 500× magnification, October sampling (left) and number and size (µm) of particles in 1 mm2 for *T. jasminoides* (right) based on 500× magnification, October sampling (right) (n = 16).

Figure 10

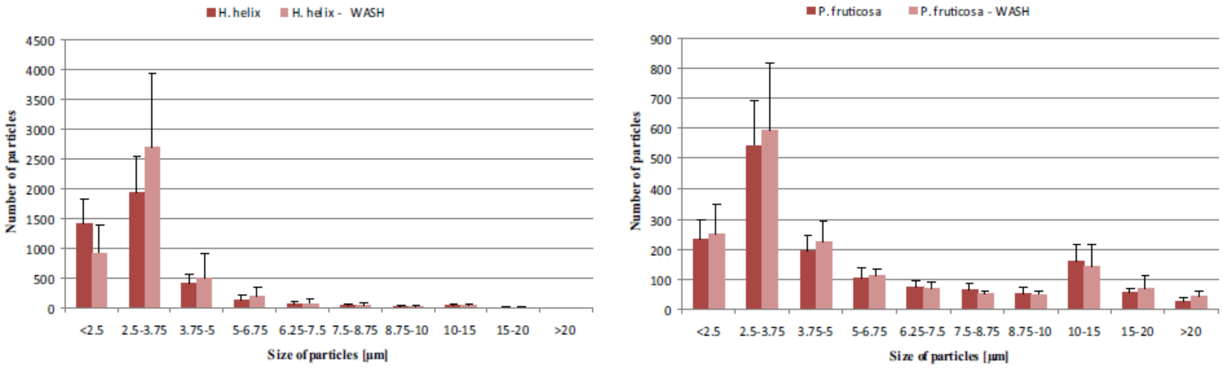


Fig. 10. Average number of particles and particle size (µm) in 1 mm2 for H. helix washed and non washed sample (left) and number of particles in 1 mm2 and particle size (µm) for *P. fruticosa* washed and non washed sample (right), based on 100× magnification (n = 32, data are mean ± SD).

Figure 11

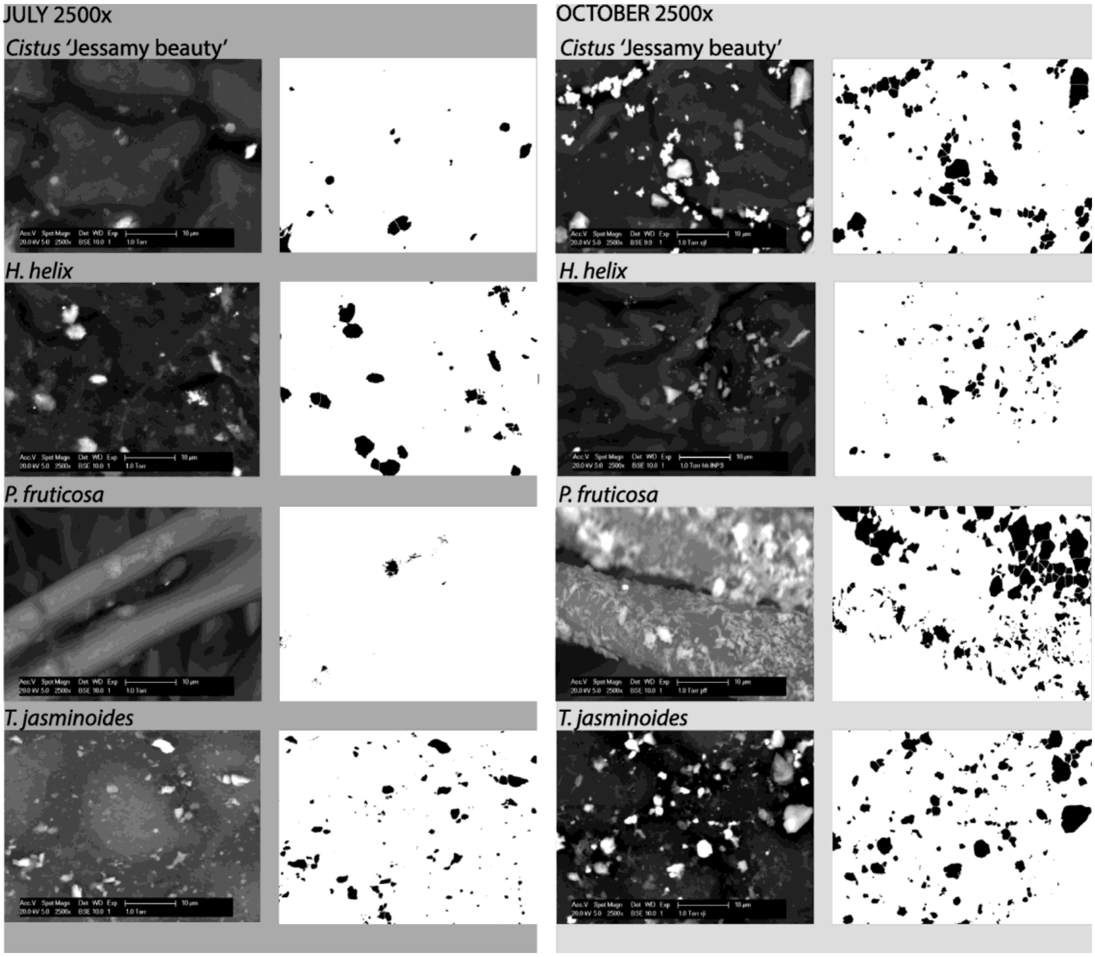


Fig. 11. *H. helix, Cistus* 'Jessamy Beauty', *P. fruticosa, T. jasminoides* 2500× magnifications.

TABLES

Table 1

Main morpho-anatomical characteristics of the considered species.

Plant species	Foliage density	leaf shape	leaf surface
Cistus 'Jessamy Beauty'	high	narrowly lance-shaped or oblong, ca. 2 cm in length	Medium hairy
Hedera helix	high	Juvenile leaf; 3–5-lobed (sampled) or adult leaf unlobed (absent in this study)	Leathery, dotted with hairs
Phlomis fruticosa	medium	Ovate, up to 12 cm in length	Densely hairy
Trachelospermum jasminoides	high	Oval, 5–8 cm in length	Waxy

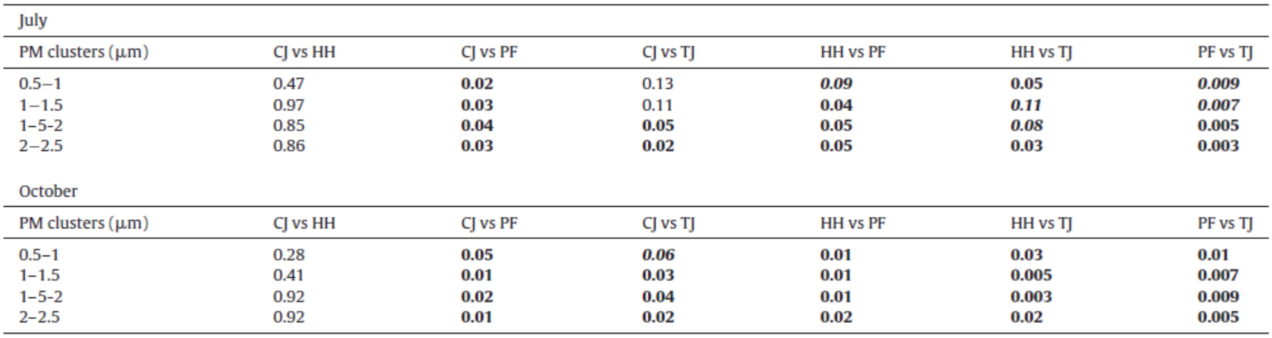
Table 2

Welch's t-test output, comparison between July and October for all the plant species analysed according to particle size. Significant values p ≤ 0.05 and p ≤ 0.10.
July vs October

PM clusters (μm)	CJ	HH	PF	TJ
0.5–1	0.29	0.54	0.25	0.38
1–1.5	0.49	0.94	0.85	0.17
1.5–2	0.63	0.71	0.85	0.20
2–2.5	0.74	0.76	0.51	0.37

Table 3

Welch's t-test output, comparison between the plant species analysed according to particle size. July and October sampling, with significant values highlighted (p ≤ 0.05 in bold and p ≤ 0.10 in bold italic).



July

PM clusters (μm)	CJ vs HH	CJ vs PF	CJ vs TJ	HH vs PF	HH vs TJ	PF vs TJ
0.5–1	0.47	**0.02**	0.13	***0.09***	**0.05**	***0.009***
1–1.5	0.97	**0.03**	0.11	**0.04**	***0.11***	***0.007***
1-5-2	0.85	**0.04**	**0.05**	**0.05**	***0.08***	**0.005**
2–2.5	0.86	**0.03**	**0.02**	**0.05**	**0.03**	**0.003**

October

PM clusters (μm)	CJ vs HH	CJ vs PF	CJ vs TJ	HH vs PF	HH vs TJ	PF vs TJ
0.5–1	0.28	**0.05**	***0.06***	**0.01**	**0.03**	**0.01**
1–1.5	0.41	**0.01**	**0.03**	**0.01**	**0.005**	**0.007**
1-5-2	0.92	**0.02**	**0.04**	**0.01**	**0.003**	**0.009**
2–2.5	0.92	**0.01**	**0.02**	**0.02**	**0.02**	**0.005**

Table 4

Elemental analysis outcome: main elements found among all the particles (n = 50 analysed for July and October sampling.

	C	O	Fe	Si	Cr	Cl	Al	Ca	Na	Mg	K	Mn	Ti	S	Mo	Cu	Ni	Br
July																		
average weight%	43.0	31.8	4.3	4.7	–	0.8	2.4	5.4	0.9	1.9	1.1	0.8	1.1	0.8	–	0.3	–	–
particles%	100	100	95	100		100	100	100	100	100	100	52	100	100		90		
Oct																		
average weight%	29.4	33.5	10.8	6.3	23.2	12.8	3.5	4.8	10.0	1.2	1.5	2.1	0.7	0.5	1.6	0.5	1.5	–
particles%	88	100	76	82	12	41	88	88	47	88	82	24	24	41	12	6	12	