Journal of Environmental Geography 16 (1–4), 31–37.

DOI: 10.14232/jengeo-2023-44584
ISSN 2060-467X

WOODY PLANTS INTERACTION WITH AEROSOL FINE PARTICULATE MATTERS AND COPPER IN BUDAPEST

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Research article, received 25 April 2023, accepted 7 July 2023

Abstract

Ambient particulate matter pollution is the primary concern as it has a significant impact on human health and the majority of the world's population lives in urban areas. Heavy metals are the most concerning component of particulate matter, and Cu is a highly traffic-related emission element whose overabundance results in toxic effects. Woody plants, on the other hand, contribute to the removal of airborne pollution in urban areas. Our aims are (1) to compare urban woody plants abilities to capture ambient fine particulate matter on leaf surface; and (2) to access the Cu concentration loads on their leaf surfaces. Consequently, our results will provide scientific knowledge for future urban planning concerning air pollution remediation. We investigated the relationship between woody plants and heavy metal pollution in Budapest. Four woody plant species were sampled at different traffic densities. Their Cu contents in the leaf and branch were measured, our results show that *Tilia tomentosa* and *Acer platanoides* are better options for ambient Cu accumulation than *Fraxinus excelsior* and *Aesculus hisppocastanus* in urban environments. At different traffic densities and sampling times, however, Cu accumulation did not vary across species. This is because, through translocation, woody plants absorb Cu not only from the air but also from the soil. Furthermore, it is also because of the long-distance transportation and long-term suspension of fine particulate matter. From the obtained results, we can conclude that woody plants are important phytoremediation elements in the urban area of Budapest. Planting *T. tomentosa* and *A. platanoides* in urban areas of central Europe will be promising for ambient heavy metal pollution phytoremediation. But environmental conditions differ from one place to another. Therefore, a comprehensive study is required in order to apply the results to different locations.

Keywords: Woody plants, Copper, Ambient pollution, Phytoremediation

INTRODUCTION

Particulate matter pollution, PM_{10} (particulate matter 10 μm) and $PM_{2.5}$ (2.5 μm), is the most prevalent pollutant in urban areas and has been a concern in recent decades because of its negative impact on the environment and public health (Abhijith et al., 2017; Li et al., 2022). Compared to large particulate matter, fine particulate matter persists in the air for a longer duration and poses a more significant threat to the environment and human health (Ferenczi and Bozó, 2017). For health considerations, the World Health Organization (WHO) suggests a daily $PM_{2.5}$ interim target of 5μg/m3 and an annual $PM_{2.5}$ interim target of 35 μg/m^3 (WHO, 2021). Among all particulate matter components, heavy metals are the most concerning because of their toxic effects (Faraji Ghasemi et al., 2020).

In urban areas, the primary sources of PM are household combustion and traffic-related emission, and road traffic emissions can contribute up to 19% of the $PM_{2.5}$ concentrations in the urban area (Ferenczi et al., 2021). In the study of Perrone et al. (2018), the $PM_{2.5}$ concentration is 17 μg/m^3 in Budapest, which is much higher than the limit of WHO's recommendation (5 μg/m^3). Thus, it is still a challenge to improve the air quality in Hungary.

Urban green infrastructure, such as street trees, vegetation hedges, and parks, is an important way to remove atmospheric particulate matter and improve air quality (Abhijith et al., 2017; Hrotkó et al., 2021; Jin et al., 2021). Despite the fact that coniferous species have been shown to have a high potential in PM trapping, they are not recommended to use as roadside trees, because they are less tolerant of high traffic-related pollution and have a difficult time surviving in the stressed urban environment, particularly if salt is used for road de-icing in the winter (Dzierżanowski et al., 2011). Thus, broadleaved trees are the better option in the aspect of tolerance the urban environment and provide pollution purifying effect in urban planning.

The ability to successfully capture PM is a crucial factor in selecting the best plant species for urban greening; therefore, it is essential to examine the fine PM capture ability of various plant species in order to optimize their use in diverse urban environments. Several studies have been carried out in different countries to estimate woody plants' potential for accumulating PM. For example, Hofman et al. (2016), discovered woody plant trapped 626 mg/m^2 of PM_{10} and 33.69 mg/m^2 of fine PM (0.2-3 μm) on the leaf surface. Jeanjean et al. (2016) reported 2.8% of atmospheric PM reduction from tree and grass leaf deposition. According to Nowak et al. (2006), urban trees removed 711,000 tons of particulate pollution in US. Several studies have conducted the accumulation of heavy metals on leaf dust deposit. Ramesh and Gopalsamy (2021) found Saraca asoca captured 235.53 mg/kg of Fe and 157.91 mg/kg of Al on the leaf surface in Kanchipuram, India. They suggest woody plants as good biomonitors for ambient heavy metal pollution. Similarly, Li et al. (2022) concluded woody plants' foliar dust could reflect the best of the ambient elemental composition by testing Pb, Zn, Cd, Cu, Ni and Mn in the foliar dust, plant leaves, surface soil, and subsoil from twenty-three plant species in Qingdao, China. El-Khatib et al. (2020) found non-essential elements, such as Pb concentrated on leaf surface dust because of aerosol deposits and plants may actively exclude them to minimize their toxic impact and leaf is a better option as a biomonitor than bark in Minya, Egypt. Kiss et al. (2017) demonstrated that heavy metal loads in tree rings can spatially and temporally reflect urban environmental conditions. However, the effect of woody plants on PM reduction and the adsorption mechanism is unknown, and direct monitoring of ambient heavy metal pollution is limited by the high cost and unreliable information on the impact of atmospheric pollutants on ecosystems (Alahabadi et al., 2017). In this study, we aim to evaluate the ability of urban plant species to capture fine particulate matter on leaf and branch surfaces. In addition, we aimed to compare their Cu deposition on the leaf surface. Thus, our findings will contribute to the species selection in the future urban planning regarding sustainable development.

MATERIALS AND METHODS

Sampling sites

Budapest, the capital of Hungary, is home to approximately two million people. It has a temperate climate influenced by both the oceanic and Mediterranean climates. The annual average temperature is 12.6 °C, with an average of 2040 h/year sunshine. The average yearly precipitation is 530 mm, with the majority of rain falling from May to June and early autumn (mean of 20 years: 2001-2020) (www.met.hu). The study area, Deák Ferenc tér is located downtown, where there is heavy traffic (Fig. 1). The Buda Arboretum is on the south slope of Gellért-Hill, which is an urban park with 7.5 ha in area and 1900 woody plant species (Schmidt and Sütöri-Diószegi, 2013)

Species and sampling

Sampling was conducted three times during the spring, summer, and autumn of 2021. Leaves and branches from four different woody plant species (*Acer platanoides*, *Aesculus hippocastanum*, *Fraxinus excelsior*, and *Tilia tomentosa*) were collected from the above mentioned two locations. The habits of these species, their leaf shapes and surface characteristic, and the measured mean area are listed in Table 1. Five trees of each species were chosen, 20 leaves and 3 second-year-old branches with a 10cm diameter were collected from each tree. After sampling, the fresh leaves and branches were dried to constant weight. Then the leaves and branches were soaked in distill water for one hour, and then shaken in an ultrasonic machine for 10 minutes. The dust suspensions were filtered by filter paper (pore size 2.5-4 μm) and evaporated until constant dryness. The weight of PM was measured with an electronic scale (Adventurer, Ohaus, Parsippany-Troy Hills, NJ, USA). The residues were then digested by a wet digestion method, applying concentrated (30%) hydrogen peroxide (H_2O_2) and

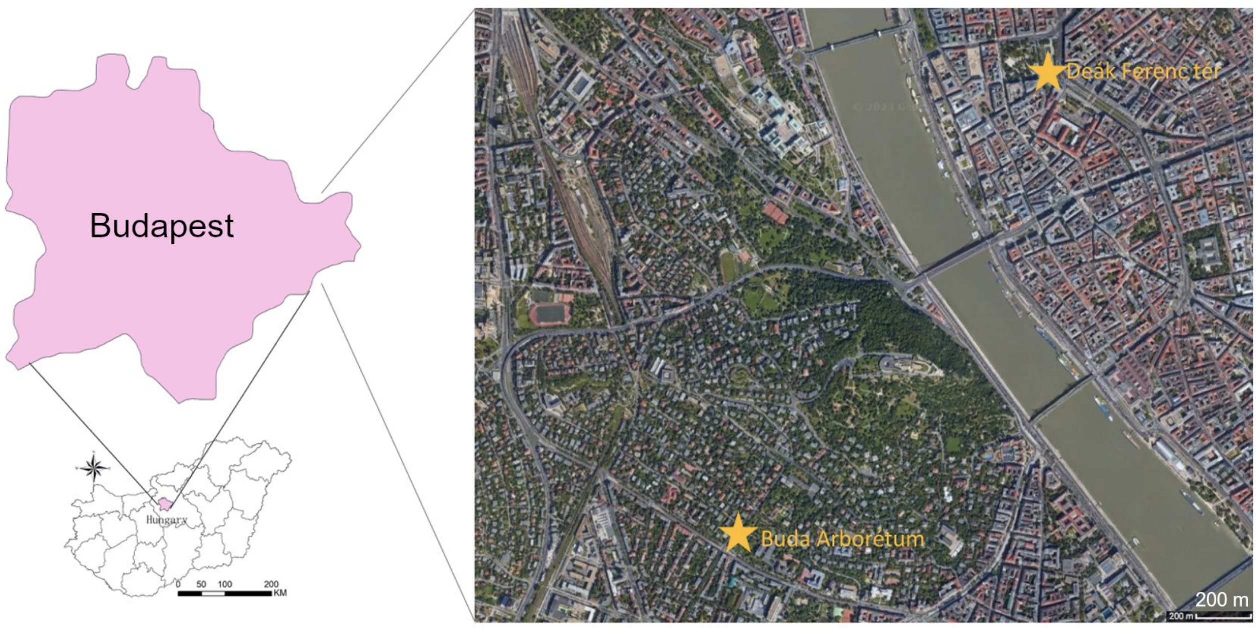

Fig.1 Sampling sites (Sources: GADM and Google maps)

Table 1 Main characteristics of the species and their leaves studied in this research

Species	Family	Leaf shape	Leaf surface	Average leaf area (cm^2)
Acer platanoides	Sapindaceae	palmately lobed leaf	glabrous	91.4
Aesculus hippocastanum	Sapindaceae	compound leaf	glabrous when mature	361.1
Fraxinus excelsior	Oleaceae	heart-shaped leaf	smooth	124.8
Tilia tomentosa	Malvaceae	compound leaf	with tomentosa	50.9

Table 2 Leaf and branch fine PM accumulation

Organ \ Species	*A. platanoides*	*A. hippocastanum*	*F. excelsior*	*T. tomentosa*
Leaf PM ($\mu g/cm^2$)	42.0 b	29.9 c	46.4 b	57.1 a
Branch PM ($\mu g/g$)	1265.5 ab	1813.2 a	694.3 b	1375.9 ab

concentrated (65%) nitric acid (HNO_3), and then diluting with distillate water to 100 ml.

An AM350 leaf area meter was used to measure leaf area (ADC Bio Scientific Ltd., UK). The real-time images and measured parameters were exported to Excel files, and then the average leaf area was computed into square meters (m2). The Cu contents were determined by an atomic absorption spectrometer (AAS) AURORA AI 1200 (Aurora Instruments Ltd., Canada).

Data analysis

The dust retention amount and mass of element per unit leaf area and per unit branch dry weight (DW) were calculated as follows (Li et al., 2022):

$$Dust\ retention\ amount = \frac{Weight\ of\ dust\ collected\ from\ each\ leaf\ sample}{Projected\ area\ of\ plant\ leaves}$$

$$Mass\ of\ element\ per\ unit\ leaf\ area\ /\ dry\ weight = Element\ concentration\ of\ foliar\ dust \times Dust\ retention\ amount$$

The dust retention amount per unit leaf area was calculated into $\mu g/cm^2$ and per unit DW in $\mu g/g$.

We used the SPSS 27.0 software package (SPSS Inc., Chicago, IL, USA) and Microsoft Excel 2017 to analyze the data set. In SPSS, the normal distribution was verified with the Shapiro-Wilk test (IBM Corp.). An independent-sample t test was used to compare the differences between two locations. A one-way ANOVA model with a Game-Howell posthoc test ($p < 0.05$) was carried out to test the differences between species and sampling times. The relationship between PM content and the mass of Cu was calculated by the Pearson correlation coefficient (two-tailed) and the curves were estimated by regression.

RESULTS

Amount of PM Loaded on Leaf Surfaces and Branches

Our results revealed that different woody plant species' capacities for PM capture are significant from one to the other (Table 2). $PM_{2.5}$ is the most harmful to human health as it travels a longer distance and suspends in the atmosphere for longer period of time (Ferenczi and Bozó, 2017; Jin et al., 2021). The PM loaded on the leaf surface and branches ranged from 5 to152 $\mu g/cm^2$ and 66.22 to 6587 $\mu g/g$ respectively, with the highest average value of 57.05 $\mu g/cm^2$ at the leaf of *T. tomentosa* and the lowest at *A. hippocastanum* and the highest average on the branch of *A. hippocastanum* and lowest on *F. excelsior*. Similarly, Jin et al. (2021) measured 27.76 to 74.89 $\mu g/cm^2$ of PM from different woody plant species. Our result also showed similar values as the study of Hrotkó et al. (2021), that *T. tomentosa* captured a higher amount of dust on the leaf surface than *A. platanoides*, followed with *F. excelsior*. The order of fine PM capture in our study was *T. tomentosa*, *A. platanoides*, *F. excelsior*, *A. hippocastanum*. This is because the characteristic features of the leaf surface highly impact the PM accumulation (Aničić et al., 2011; Norouzi et al., 2015; Nadgórska–Socha et al., 2017; Choi et al., 2021). The abaxial surface of the leaf appears to retain a higher number of fine PM than the adaxial surface, because such a leaf components, like trichomes and granulated epicuticular wax layer increase the PM accumulation (Chen et al., 2017; Gajbhiye et al., 2019). Considering presence of tomentosa at the abaxial surface of *T. tomentosa*, this may result in a higher concentration of fine PM than in other species. PM accumulation on branches also shown noble difference between species, as *A. hippocastanum* had the highest values, followed by *A. platanoides* and *T. tomentosa*, and the lowest values were measured for *F. excelsior*. It is because the differences between branch surface.

The PM contents of foliar dust and branch dust were not significantly different between locations of the same species (Fig. 2). This is in contrast to other studies, as Sevik et al. (2019) and Aricak et al. (2020) stated that traffic density significantly influences PM deposition on

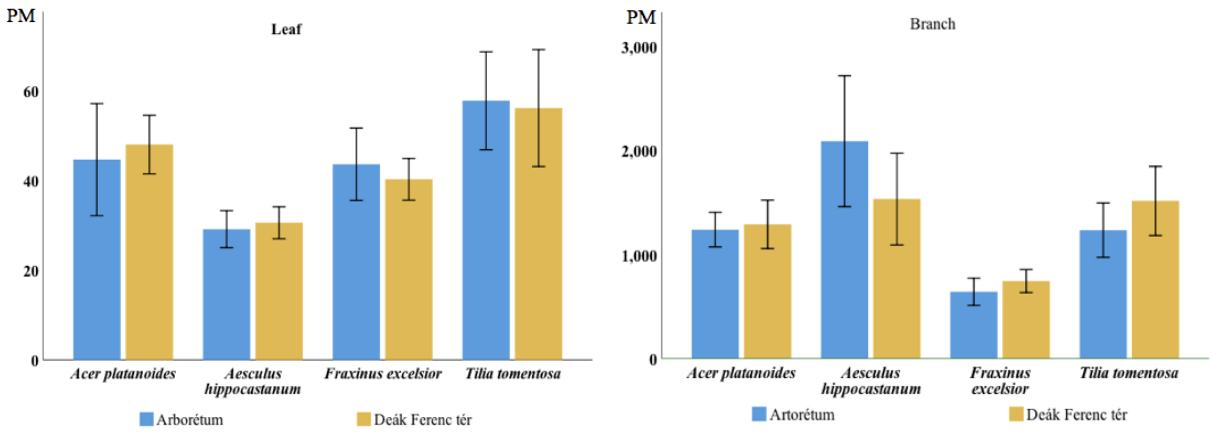

Fig.2 PM concentration on the leaf surface (μg/cm^2) and branch surface (μg/g)

leaf surfaces. Because fine PM has a lifetime ranging from days to weeks and may travel large distances, including across borders (Ferenczi et al., 2021). Furthermore, fine PM captured on the leaf surface is harder to wash off by rainfall or blow off by wind, as the fine PM accumulates inside stomata rather than depositing over the epidermal and stomata surfaces (Gajbhiye et al., 2019). Thus, within a metropolis, the difference between two places with varying traffic densities may not produce statistically significant findings.

Our results agreed with those of Jin et al. (2021), i.e., that species are significantly different in PM capturing. The growth parameters of plants also influence the deposition of PM on the foliar and branch surfaces (Mori et al., 2015). Although the biomass of the branch is not as big as that of the leaves, which can be considered in phytoremediation or phytoextraction, it is also recommended to monitor the atmospheric deposition because it reflects the exposure period of time and forms annual segments that can be easily distinguished (Drava et al., 2017).

Mass of Copper on Foliar and Branch Dust

The mass of Cu on leaf and branch surfaces is shown in Table 3. The Cu content of foliar dust ranged from 0.64 to 51.18 μg/g, and no significant differences were found between leaf surfaces of the species. While the branch dust ranged from 33.9 to 280.44 μg/g with significant differences, it was the highest at *T. tomentosa*, followed by *A. platanoides* and *A. hippocastanum*, and the lowest at *F. excelsior*. Cu is a necessary element for plant growth. In the ambient, the main source of Cu is from the high rate of brake abrasion because of increased stopping and low speeds of vehicles (Świetlik et al., 2013). The result of branch dust in this study, whose average ranges from 61.2 to 145.38 μg/g, is similar to the study of Świetlik et al. (2013), as the Cu concentration in the road dust from Poland was 152 μg/g. While the Cu content in the foliar dust was much lower, this might indicate that Cu loaded on the leaf surface can be translocated into the leaf and used for plant growth.

The comparison of Cu content between two locations showed no significant difference between the species in both foliar and branch dust (Table 4). This corresponds to the result of PM content. Thus, we can conclude that fine PM and Cu contents did not show a significant difference between an urban park and a heavy traffic area.

We further compared the differences between different seasons. The statistical results indicated differences between seasons for all species (as Table 5). The foliar dust of *A. platanoides* and *T. tomentosa* showed the same trend, being the highest in spring and lowest in summer, while *A. hippocastanum* showed the opposite trend, and *F. excelsior* did not have significant differences in all seasons.

Human activities release large quantities of heavy metals into the atmosphere; these heavy metals are easily adsorbed onto particulate matter in the atmosphere and then retained on plant leaves, resulting in extremely high concentrations of heavy metals in foliar dust (Li et al., 2022). Our results show the content of Cu in foliar dust was below the toxic level and the Hungarian soil background value [6/2009. (IV.14.) KvVM- EüM-FVM] as well; however, the content on the branch exceeded the background value and pollution limit value (Csorba et al., 2014).

Table 3 Copper concentration of foliar and branch dust (μg/g)

Species	*A. platanoides*	*A. hippocastanum*	*F. excelsior*	*T. tomentosa*
Leaf	14.9±13.1 a	13.14±8.2 a	15.3±9.9 a	13.1±9.5 a
Branch	102.4±31.5 b	89.9±33.6 bc	61.2±21.2 c	145.3±57.1 a

Note: Letters indicate significant differences between species ($p<0.05$).

Table 4 Difference of copper contents of foliar and branch dust by locations (μg/g)

Species	Location	*A. platanoides*	*A. hippocastanum*	*F. excelsior*	*T. tomentosa*
Leaf	Aboretum	15.2±6.6	15.1±9.7	17.3±12.9	12.9±9.4
	Deák Ferenc tér	14.6±9.2	11.2±6.4	13.3 ±5.5	13.3±10.0
	Aboretum	116.7±35.6	88.2±34.9	52.5±12.1	172.6±67.8
Branch	Deák Ferenc tér	88.1±19.3	91.6±33.7	69.8±25.2	118.1±24.3

Note: Letters indicate significant differences between species ($p<0.05$).

Table 5 Difference of copper contents of leaf and branch dust by sampling time (μg/g)

Species	SamplingTime	*A. platanoides*	*A. hippocastanum*	*F. excelsior*	*T. tomentosa*
Leaf	Spring	19.9±7.2 a	8.4±6.3 b	12.6±6.6 a	19.6±8.8 a
	Summer	7.6±2.0 b	18.4±5.5 a	19.3±6.6 a	5.2±4.0 b
	Autumn	14.8±7.9 ab	12.5±3.8 ab	14.0±5.7 a	14.5±6.1 ab
Branch	Spring	123.8±36.8 a	104.7±30.6 a	62.9±18.9 ab	178.0±80.7 a
	Summer	87.6±23.5 b	59.3±13.5 b	44.0±11.1 b	140.5±28.5 a
	Autumn	95.7±23.2 ab	105.7±31.3 a	76.6±19.7 a	117.5±36.0 a

Note: Letters indicate significant differences between sampling time ($p<0.05$).

Relationships Between the PM and Cu mass on Leaf Surface

Considering there were significant differences between PM capture on the foliar dust, but no difference between the Cu contents, we further analyzed the relationships between the PM content and Cu mass in the foliar dust. The Cu content of foliar dust from all species tested had a significant correlation with the mass fine PM deposition ($R^2 >0.5$), with the strongest correlation in F. excelsior ($R^2 =0.794$) (Fig. 3). This corresponded to the study of Mori et al. (2015), the PM on the leaf surface and the element load share similar characteristics. Thus, the deposition of elements is highly related to the PM accumulation on the leaf surface; however, the plants uptake elements not only from the soil but also translocate them from the leaf surface (Serbula et al., 2013; El-Khatib et al., 2020).

DISCUSSION

More than half of the world's population resides in urban areas, making the urban green future crucial (Abhijith et al., 2017). Urban green infrastructures are contributing several benefits. Proper plant species should be able to tolerate the extreme urban environment, such as shade, drought, poor soil, continuous pruning, and air pollution (Szaller et al., 2014). Despite that, suitable species will provide ornamental value, generate environmental benefits, and provide health benefits (Ulmer et al., 2016; Turan et al., 2020). The ability of woody plants to accumulate PM in urban areas is determined by various aspects, including the physical and chemical properties of PM, hazardous element forms, leaf shape, the biological status of plants, leaf surface, the exposure period, and ambient conditions. Urban design requires a comprehensive examination of the ambient conditions as well as the capacity of woody plants to tolerate the urban environment and provide PM filtration benefits. Our preliminary results evaluated woody plants' potential for fine PM accumulation in urban areas of Budapest. *T. tomentosa* showed higher ability in PM capturing than other species, and there was no significant difference between two locations in all species. In the case of Cu deposits, there were no significant differences between species or the same species in different locations. Which might be because Cu can be incorporated into leaves. In the future, more work is needed to confirm the uptake of Cu in the woody plants' leaves. Estimating the total amount of PM deposits in a tree will provide useful information about the phytoremediation efficiency of air pollution.

CONCLUSION

Massive quantities of airborne particulate matter are produced by human activities, endangering the health of the majority of the world's population. On the other hand, urban ecological infrastructures are promising for PM procurement. Leaf and branch dust are essential air pollution monitoring parameters due to their low cost and effectiveness. Our study assessed the ability of prevalent woody plant species in Budapest to capture PM in their leaves and branches. We also investigated the Cu contents, this study's findings for all species did not reveal elevated Cu pollution levels in Budapest. Furthermore, we analyzed the relationship between Cu and the PM deposit. Our findings also demonstrate that leaves are effective at absorbing ambient elements. In Budapest, *T. tomentosa* is considered more effective at fine PM capture than *A.*

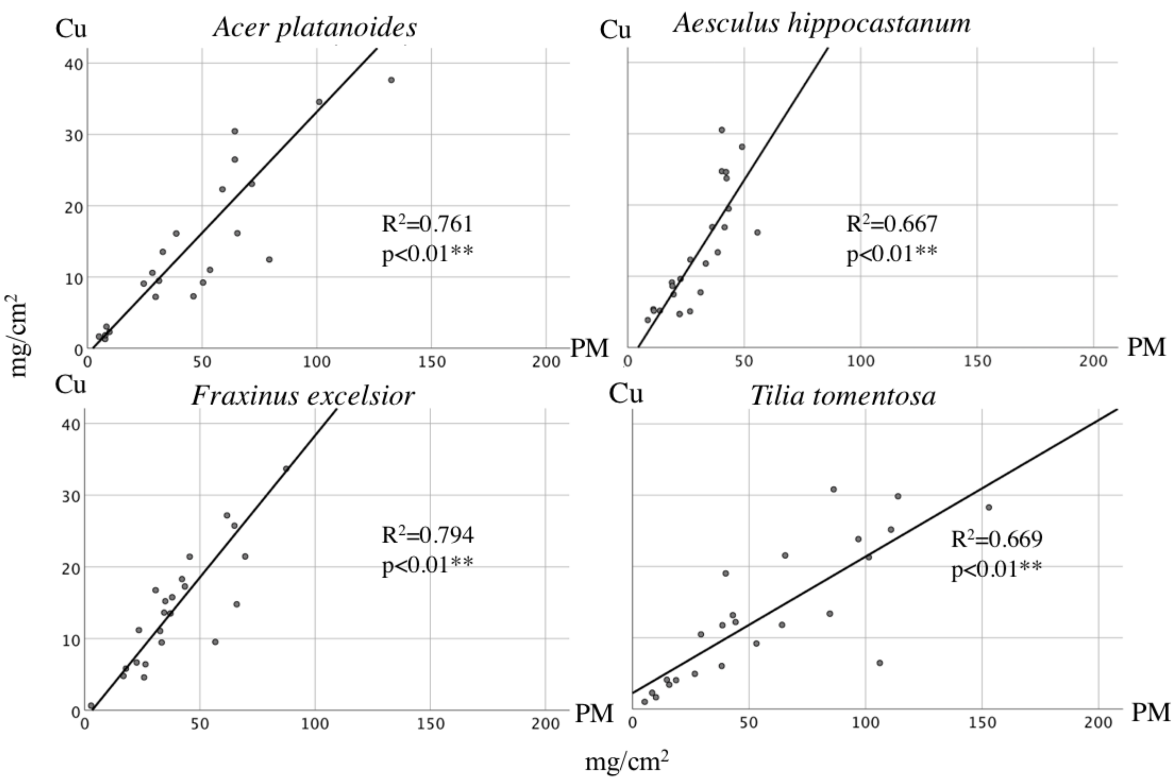

Fig. 3 Relationship between PM and Cu load on woody plant leaf area

platanoides, *F. excelsior*, and *A. hippocastum* in terms of tree species selection. Calculating the quantity of PM that trees and urban woody plants absorb and the mechanism by which trees translocate atmospheric heavy metals can be the focus of future research. Identifying the sources of PM and the dangers to human health is also essential.

ACKNOWLEDGEMENT

We thank to the Hungarian University of Agriculture and Life Sciences.

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