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Differences in accumulation of PAHs and metals on the leaves of *Tilia×euchlora* and *Pyrus calleryana*

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"Capsule": *PAHs and metals accumulated more on linden (Tilia×euchlora) than pear (Pyrus calleryana) leaves.*

Abstract

The accumulation of substances associated with $PM_{2.5}$ [polycyclic aromatic hydrocarbons (PAHs) and metals] on leaves of *Pyrus calleryana* (pear) and *Tilia×euchlora* (linden) along an urban road was investigated. These species have similar leaf morphology and were exposed to the identical environmental conditions. The accumulation of both PAHs and metals per leaf area was significantly higher on linden leaves than on pear leaves.

Keywords: $PM_{2.5}$; Metals; PAH; Epicuticular waxes; Atmospheric air pollution

1. Introduction

Particles less than 2.5 μm ($PM_{2.5}$) in aerodynamic diameter are of special concern in terms of environmental health (Anderson et al., 1996; Sram et al., 1996). Due to a high volume to mass ratio and small size, $PM_{2.5}$ can absorb or adsorb large amounts of toxic compounds and remain suspended in the troposphere for relatively long periods, presenting a potential danger for human health. When inhaled, these aerosols are not trapped in the upper respiratory system, but are deposited directly in the alveoli in the lungs, where their residence time can be months or years (Phalen, 1984). Polycyclic aromatic hydrocarbons (PAHs) and metals are associated with $PM_{2.5}$ (US EPA, 1996; Poster et al., 1995) and increase the potential health impact of these particles. Direct correlation between the amount of $PM_{2.5}$ in the air and human health has been shown (Department of Health, 1995; Holian, 1996; Talaska et al., 1996; Sram et al., 1996; Dockery et al., 1993; Schwartz et al., 1996).

Trees can reduce the amount of $PM_{2.5}$ by intercepting and retaining these particles on their leaf and bark surfaces. Even though more than 80% of forests in the northeastern United States is deciduous (Alerich and Drake, 1995), few researchers have investigated the effect of deciduous tree leaves on removing fine particles from the atmosphere. This limited research is likely due to the various shapes and sizes of deciduous leaves, which cause difficulties in interpretation of results. Smith (1981) suggested that smaller leaves have higher ability to accumulate and retain particles than bigger ones. Simonich and Hites (1994) referred the lipid content of vegetation as a measure of the total capacity for sorption of lipophilic semi-volatile organic compounds (SOCs) to vegetation. Howsam et al. (2000) showed that deciduous leaves with trichomes had a significantly higher total PAH concentration than hairless leaves. However, the results of this study were obtained by measuring the concentration of PAHs per leaf dry weight rather than leaf area. Since leaves of different species may vary in the amount of biomass per leaf area, the use of dry weight measurements does not give an accurate picture of accumulation of toxins on leaves.

The accumulation of metal has been investigated more extensively. It has been shown that some deciduous species can be used as bio-indictors of elevated concentrations of certain metals in the atmosphere

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(Sanka et al., 1995; Schumacher et al., 1998; Alshaev et al., 1995).

Previous research has often focused on either PAHs or metals accumulated on tree leaves. Recent work has shown that particles containing both PAHs and metals are able to induce higher oxidative stress conditions than either substance alone in human lung cells (Garcon et al., 2000).

Accumulation of PAHs in vegetation depends on the properties of the particular PAH as well as on the properties of the accumulating surface (Komp and McLachlan, 1997; Bohme et al., 1999) and on environmental conditions (Franzaring, 1997). The accumulation of SOCs in plants is primarily determined by one of the following processes: (1) equilibrium partitioning for the compounds with the log of octanol-air partition coefficient (K_{OA}) $< \sim 9$; (2) kinetically limited gaseous deposition for the compounds with $9 < \log K_{OA} < 11$; or (3) particle bound deposition for substances with log $K_{OA} > 11$ (McLachlan, 1999, Welsch-Pausch et al., 1995; Paterson et al., 1991).

Plant–air partition coefficients (K_{PA}) for a range of PCB congeners varied by a factor of 20 among five different grass and herb species (Komp and McLachlan, 1997), revealing that the lipophilicity of epicuticular waxes of grasses is often different from octanol and can vary widely among plants.

The determination of what components of epicuticular waxes enable the accumulation of particles is very important. Currently, little research has quantified interspecies differences among deciduous species in terms of the composition of their waxes. Gulz's work indicates that generally the composition of waxes is only slightly different within the same genus (Gulz et al., 1988). There are, however, striking differences in the composition of waxes between deciduous species (Gulz, 1994; Challice et al., 1980). *Tilia tomentosa*, for example, has greater amounts of triterpenoids than other deciduous species; β-amyrenyl acetate comprises 49% of the wax of mature leaves (Gulz et al., 1991).

The purpose of the present research was to investigate the differences in accumulation of both PAHs and metals on leaves of two deciduous species (which have similar leaf size and leaf morphology) over the growing season—*Pyrus calleryana* and *Tilia×euchlora*.

2. Materials and methods

2.1. Materials

Organic solvents used in the experiment: Hexane-98.5% HPLC grade (Fisher Scientific); Methanol-HPLC/GC grade (Mallinckrodt UltimAR); Dichloromethane (DCM)-99.5% GR grade (EM Science); Acetone-99.4% Ultra-Resi-Analyzed for Organic Residue Analysis (J.T. Baker); and Toluene-99.9% OmniSolv glass distilled (EM Science), Tetrahydrofuran-99% Certified (Fisher Scientific).

Inorganic substances used: potassium hydroxide, pellets, Baker Analyzed ACS Reagent, low in chloride (J. T. Baker). Nitric acid was GR grade (68–70%, EM Scientific). Five-percent or concentrated nitric acid was used in analysis for metals. Sodium sulfate [GR grade, Anhydrous, Granular, (EM)] was heated for 6 h at 450 °C and stored in desiccator prior to usage.

Silica gel (70–230) mesh, type 60 Å, (Merck) was activated at 250 °C for 24 h, cooled in a desiccator, and then deactivated with distilled water (10% w/v). Silica gel was used within 48 h of preparation. Sixteen grams of silica gel were packed into a glass column (15 mm i.d.×70 cm) with the use of hexane. Air pressure was applied to blow air bubbles from the column and speed up the elution during the separation.

A mixture of PAH standards, 98% purity, Ultra Scientific, contained 16 compounds (abbreviation and molecular ion are given in parentheses) and specified in EPA Method 610: naphthalene (Nap, 128), acenaphthylene (Ay, 152), acenaphthene (Ae, 154), fluorene (Flr, 166), phenanthrene (Phe, 178), anthracene (Ant, 178), fluoranthene (Flu, 202), pyrene (Pyr, 202), benz (a)anthracene (B(a)a, 228), chrysene (Cry, 228), benzo(b)fluoranthene (B(b)f, 252), benzo(k)fluoranthene (B(k)f, 252), benzo(a)pyrene (B(a)p, 252), indeno(1,2,3-cd)pyrene (Ind, 276), dibenz(a,h)anthracene (Di, 278), and benzo(ghi)perylene (B(g,h,i)p, 276). PAH standard mixtures were prepared (with hexane as a solvent) from a stock solution of 200.0 μg/ml of PAH mixture in toluene and stored at 4 °C. The internal standard (95% purity, Ultra Scientific) benzo(b)fluorene (IS) was prepared as a stock solution containing 2.00 μg/μl in toluene and stored at 4 °C.

All glassware for PAH analysis was soaked with "Micro" concentrated cleaning solution for critical cleaning (International Products Corporation, USA), rinsed with distilled water, and then with acetone and hexane prior to use. Glassware for metal analysis was rinsed three times with 10% nitric acid prior to analyses or storage of samples.

2.2. Sampling site and collection strategies

The study location was a major road in Syracuse, NY, USA. As predominant winds are from the west in Syracuse, an east–west orientation of the street helped ensure similar exposure of study trees to both particulate and gaseous atmospheric air pollutants.

Selected for the study deciduous tree species grew beside the studied road: *Tilia×echlora* (linden) and *Pyrus calleryana* (pear). These trees had similar crown shape, leaf size and shape, crown density (McPherson, 1984), morphology of leaf surface, and were approximately the

same age. Four trees of each species growing on opposing sides of the road (1–2 m from the curb) were sampled with leaves collected from each of four sides of the trees. Leaves were taken from the middle part of branches located at 2–3 m height from the ground. Sampling was carried out twice a month, from May through late September 1998, between the hours of 09:00 and 11:00. A composite of all leaves from the four trees resulted in one sample for analysis. Several composite samples were collected for each sampling date in order to have enough replicates. The leaves were stored in solvent rinsed glass jars at −20 °C. Samples were also collected a few hours after a major windstorm on 7 September 1998 (precipitation: averaged over 24-h period—1.05 inches of water; highest wind speed: averaged over 5 s—77 miles/h, averaged over 2 min—59 miles/h).

2.3. Sample treatment and analysis

2.3.1. Leaf area, dry weight measurements

To ensure accurate comparisons of the air pollutants on leaves of the two species, both leaf surface area and dry weight measurements were taken. Projected (one side) leaf areas were measured using *Metamorph Image Analysis* software. For each sampling date two replicates of 24 leaves for each species were randomly selected. After area measurements, leaves were oven dried at 105 °C for 24 h and then cooled in a desiccator. Dry-weight measurements were taken and leaf area to dry weight ratios (square decimeter per gram, dm^2/g) were determined.

2.3.2. Epicuticular wax extraction

Leaf waxes were extracted with chloroform (Gulz, 1994) for 15 min followed by a second extraction for 5 min. The wax extracts were transferred to tared vials, dried, and weighed. Using area/dry weight measurements, results were presented as milligrams of wax per leaf surface area (mg/dm^2).

2.3.3. Gas chromatography/mass spectrometry (GC/MS) method and sample preparation

Two replicates of composite samples (50.0 g of fresh leaves each, for each sampling date) were cut into small pieces and placed in a closed jar with 200 ml of 2 M KOH in methanoic solution (methanol to water, 9:1) for 3 h. The extract was filtered through a pre-rinsed Buchner porcelain filter funnel (without a filter paper) in order to separate leaves from the extract. The extract was diluted with 200 ml of water. This mixture was subjected to partition extraction with 100 ml of hexane, followed by two additional extractions, 50-ml each, with hexane. Hexane extracts were combined and washed twice with 200 ml of water, dried with anhydrous sodium sulfate overnight, and evaporated to 1 ml with a Kuderma-Danish evaporator. Five (5.00) micrograms of internal standard (IS) were added to all samples and standards to account for the loss of PAHs during further clean up procedure and for quantification. The concentrated extract was subjected to separation of PAHs from aliphatic hydrocarbons and polar substances present in epicuticular waxes using a Silica gel column. The sample was carefully placed on the top of the column using a Pasteur pipet. Sixty milliliters of hexane were used for the elution of alkanes. The alkane fraction was discarded. Eighty milliliters of 25% dichloromethane in hexane were used to elute all 17 PAHs in one fraction. The fraction containing PAHs was evaporated to a volume of 0.5 ml by bubbling nitrogen gas through the sample and then transferred to a labeled GC/MS vial.

For the separation and identification of the PAHs, a Hewlett-Packard 5890 gas chromatograph interfaced to a 5972A Mass Selective detector was used. Quality control samples (standards prepared from an independent source of stock solution) were run after every sixth sample. The injection technique was split/splitless at 300 °C. The column had the following parameters: 30 m×0.25 mm i.d. with a 0.25 μm thick stationary phase film of 5% phenyl substituted polydimethylsiloxane. The single ion monitoring (SIM) mode of acquisition was used. The carrier gas was helium. Both temperature and pressure programming were used in PAH analysis. The column oven temperature was held at 64 °C for 2 min, then ramped at 8 °C/min to 290 °C, and held at that temperature for 27 min. The following pressure programming was used in the experiment: initial pressure—12 psi for 2 min, increased 0.3 psi/min to 24 psi, and held at 24 psi for 15 min. PAHs were quantified using relative response factor to the internal standard, reported as nanograms per gram of dry weight (ng/g dw), and then, using leaf area/dry weight measurement, converted to nanograms per square decimeter (ng/dm^2) for each sampling date.

2.3.4. Inductively coupled plasma (ICP) method and sample preparation

Ten (10.0) grams of fresh leaves (two replicates for each sampling date and species) were placed into 250-ml Erlenmeyer flasks and shaken in 75.0 ml of 5% HNO_3 acid solution on a reciprocal shaker-table for 90 min. Samples were filtered through filter paper (Whatman #1) and stored in plastic bottles. Five-percent nitric acid was used as a solvent in preparation of standards, blanks (5% HNO_3 passed through the procedure without a sample), and quality control samples (standards prepared from an independent source of stock solution). All glassware for metal analyses was rinsed three times with 10% HNO_3 prior to usage.

Samples were analyzed for Cd, Cr, Cu, Fe, Ni, Pb, Ti, V, and Zn using an ICP emission spectroscopy (Perkin Elmer 3337, AS-90) with background correction. A

quality control sample was run after every seventh analysis. Metals were measured as micrograms per gram of dry weight (μg/g dw) and then, using leaf area/dry weight measurement, converted to micrograms per square decimeter of leaf area (μg/dm^2) for each sampling date.

2.4. Statistical analyses

2.4.1. Leaf areas, waxes

The means of leaf areas of linden (μ_L) and pear (μ_P) for all sampling dates were compared using a two-sample *t*-test ($\alpha = 0.05$). The same statistical method was used to compare leaf area per dry weight measurements for the two species ($\alpha = 0.05$). A paired *t*-test was used for the comparison of amounts of waxes on leaves (pared for each sampling date, $\alpha = 0.05$).

2.4.2. PAHs and metals

A non-parametric one-sample Wilcoxon test for paired samples was used to test for the differences in PAHs and metals between leaves of linden and pear trees ($\alpha = 0.05$).

3. Results

3.1. Leaf areas

The average leaf areas of linden and pear over the growing season were not significantly different (Table 1). Linden leaves had a higher ratio of leaf area per gram of dry weight (dm^2/g dw) for each month (Table 2).

Table 1
Comparison of average leaf areas of linden and pear leaves

Species	*N*	Mean (cm^2)	*P*	DF
Linden	151	28.42±1.27	0.83	300
Pear	151	28.18±1.23		

Two sample *t*-test: $\mu_L - \mu_P = 0$ vs. $\neq 0$; 95% CI $\mu_L - \mu_P$: (−1.86, 2.33).

Table 2
Comparison of the average leaf area per gram of dry weight of linden and pear

Dates (1998)	*N*	Linden (dm^2/g dw)	Pear (dm^2/g dw)
27 May	24	1.75±0.26	1.17±0.18
22 June	24	1.76±0.20	1.10±0.08
17 July	24	1.51±0.21	0.87±0.09
28 July	31	1.47±0.17	0.76±0.10
28 August	24	1.57±0.17	0.91±0.07
26 September	24	1.48±0.17	0.72±0.08

Two-sample *t*-test: $\mu_L - \mu_P > 0$ vs. $\leqslant 0$; *P*-value = 0.000.

3.2. Epicuticular waxes

The amounts of epicuticular waxes on the leaves for five sampling dates (May–beginning of July) were higher (*P*-value 0.046) on pear leaves (0.70±0.09 mg/dm^2) than on linden leaves (0.51±0.02 mg/dm^2). Later sampling dates were not considered in order to avoid interference of honeydew deposits of aphids on linden leaves with wax measurement.

3.3. PAHs per leaf area

PAHs were grouped, based on their partitioning (Harner and Biddleman, 1998) between particulate and gaseous phases, into three groups (Table 3):

1. low molecular weight (LMW)—PAHs that exist mostly in the gaseous phase;
2. medium molecular weight (MMW)—PAHs that partition between particulate and gaseous phases depending on the environmental conditions;
3. high molecular weight (HMW)—PAHs that exist mostly in the particulate phase.

No differences between the species were observed for LMW PAHs. However, linden had statistically higher concentrations of some MMW (3 of 6 PAHs analyzed) and all HMW (6 of 6 PAHs) PAHs.

The distribution of HMW PAHs on leaves of linden and pear over the growing season is depicted in Fig. 1. Note that the storm substantially removed HMW PAHs from the surface of leaves, and that the concentrations of HMW PAHs in hottest months (June and July) are low.

3.4. Metals per leaf area

No detectable amounts of Cr, Ni, or V were found on leaves of either species.

Accumulation of all other analyzed metals (except for cadmium) was significantly greater on linden than on pear tree leaves (Table 4).

4. Discussion

4.1. Leaf areas

Since average leaf areas (Table 1) are similar between the two species, differences in the accumulation of PAHs and metals cannot be attributed to the difference in leaf sizes but rather to some properties of the leaf surfaces, or the amounts of waxes, or both.

Comparison of ratios of leaf area per dry weight (Table 2) for the two species shows that these ratios can vary over the growing season for each of the species and

Table 3
Results of Wilcoxon test for the median of differences of monthly means of PAH concentrations on leaves of linden and pear[a]

PAHs	N	Log K_{OA}[b]	P-value Wilcoxon $\alpha = 0.05$	Estimated median of difference	Linden mean (ng/dm^2)	Pear mean (ng/dm^2)	Ratio of means Linden/Pear
LMW							
Naphthalene	6	5.01	0.85	−0.53	1.1±0.5	1.4±1.4	0.8
Acenaphthene	6	7.73	0.42	0.11	1.9±0.6	1.6±0.9	1.2
Acenaphthylene	6	8.02	0.58	−0.11	0.7±0.2	0.7±0.3	1.0
Fluorene	6	8.18	0.74	−0.75	4.0±0.7	4.5±1.5	0.9
MMW							
Phenanthrene	*6*	*9.20*	*0.02*	*17.93*	*51.3±14.1*	*31.8±10.3*	*1.6*
Anthracene	6	9.25	0.15	0.30	3.0±0.7	2.8±0.8	1.1
Chrysene	6	9.69	0.42	1.43	31.1±6.0	31.9±8.5	1.0
Fluoranthene	6	9.74	0.74	−4.29	48.4±5.2	28.0±6.1	1.7
Pyrene	*6*	*10.08*	*0.03*	*10.94*	*27.2±3.8*	*14.8±3.9*	*1.8*
Benz(a)anthracene	*6*	*11.14*	*0.02*	*3.50*	*7.7±1.0*	*4.6±0.6*	*1.7*
HMW							
Benzo(b)fluoranthene	*6*	*10.08*	*0.02*	*7.21*	*12.8±1.5*	*6.5±0.8*	*2.0*
Benzo(a)pyrene	*6*	*11.92*	*0.02*	*4.00*	*6.7±0.8*	*3.3±0.5*	*2.0*
Benzo(k)fluornathene	*6*	*12.21*	*0.05*	*4.66*	*11.2±1.5*	*7.0±0.9*	*1.6*
Indeno(1,2,3-cd)pyrene	*6*	*12.38*	*0.02*	*4.00*	*6.8±0.9*	*3.5±0.6*	*1.9*
Benzo(ghi)perylene	*6*	*13.43*	*0.03*	*4.77*	*9.4±1.3*	*5.0±1.0*	*1.9*
Dibenz(a,h)anthracene	*6*	*14.33*	*0.02*	*1.33*	*2.0±0.7*	*0.7±0.3*	*2.9*

[a] Median = 0 vs. median > 0. Results in italic indicate significant difference.
[b] Octanol–air partition coefficients of the PAHs were calculated using Henry's Law constants and octanol–water partition coefficients compiled by the Syracuse Research Corporation.

Table 4
Results of Wilcoxon test for the median of differences of monthly means of metal concentrations on leaves of linden and pear[a]

Elements	P-value $\alpha = 0.05$	Estimated median of differences of means (μg/dm^2)	Linden mean (μg/dm^2)	Pear mean (μg/dm^2)	Ratio of means Linden/Pear
Cd	0.85	−0.03	0.16±0.01	0.20±0.02	1.1
Fe	*0.02*	*16.8*	*29.29±3.14*	*12.30±1.04*	*2.4*
Ti	*0.02*	*0.08*	*0.18±0.02*	*0.10±0.03*	*1.8*
Zn	*0.02*	*0.09*	*0.43±0.05*	*0.26±0.03*	*1.7*
Pb	*0.02*	*1.14*	*2.88±0.34*	*1.28±0.16*	*2.3*
Cu	*0.02*	*0.75*	*1.69±0.28*	*0.76±0.15*	*2.2*

[a] Median = 0 vs. median > 0. Results in italic indicate significant difference.

between the species. Linden leaves have more surface area per gram of dry weight than pear tree leaves ($P = 0.000$, Table 2). This observation is an additional proof that comparisons of pollutant accumulation on leaves need to be assessed on the basis of leaf surface area rather than dry weight measurements.

4.2. Epicuticular waxes

As can be seen from the results, the pear tree leaves have higher amounts of wax but lower amounts of particulate air pollutants. This finding indicates that factors other than the amount of wax (Simonich and Hites, 1994) can influence the accumulation of fine particles on leaves. More research is needed to develop a better procedure of wax removal from leaves. The impact of the composition of tree waxes on accumulation and retention of fine particles needs to be further investigated as well as the importance of other environmental factors.

4.3. PAHs on leaves

Atmospheric concentrations of PAHs were not measured, but were assumed to be the same for both species since study trees were located along the same road within 20 m of each other. The amounts of LMW PAHs on leaves were not significantly different between species. This result corresponds with research by McLachlan and Horstmann (1998) and Howsam et al. (2000).

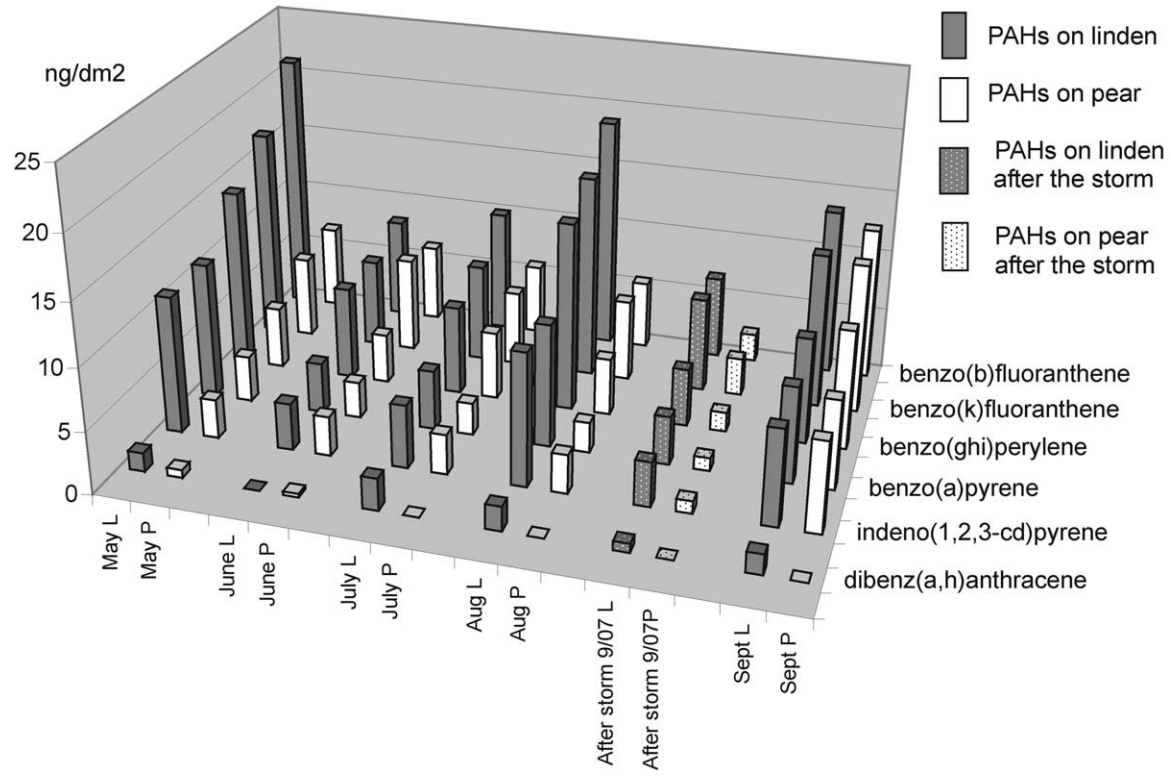

Fig. 1. HMW PAHs per leaf area over the growing season, 1998.

According to McLachlan and Horstmann (1998), volatile PAHs with log $K_{OA} < 7$ are not likely to be accumulated in the forest canopy.

The difference between the amounts of three MMW PAHs—chrysene, anthracene, and fluoranthene—on leaves of the two species was not statistically significant. The accumulation of these PAHs may be governed by kinetically limited dry gaseous deposition (McLachlan, 1999). There is likely very little interspecies variability in the accumulation of semivolatile organic compounds in this accumulation mode (Bohme et al., 1999).

The amounts of other MMW PAHs—phenanthrene, pyrene, and benz(a)anthracene—were statistically higher on linden than on pear tree leaves (Table 3). The uptake of phenanthrene (log $K_{OA} = 9.20$) by plants is likely controlled by equilibrium partitioning that results in pronounced accumulation in vegetation (McLachlan, 1999). It is possible that linden leaves possess a higher ability to accumulate PAHs by this mechanism.

The accumulation mode of pyrene, benz(a)anthracene, and all HMW PAHs (log K_{OA} values > 10) most likely follows the particle bound deposition. The notable difference in accumulation of the PAHs by the two species (the ratio of means for these PAHs is equal to two; Table 3) can be attributed to the fact that linden leaves have a higher ability to accumulate and retain particles than pear leaves. As HMW PAHs are mostly present in particles of a size less than 1.4 μm in aerodynamic diameter (Poster et al., 1995), it is probable that linden leaves accumulate more fine-particle-associated PAHs than pear leaves.

Fine-particle-associated HMW PAHs were removed from the leaves of both species (Fig. 1) by the actions of rain and wind after the storm event. This observation confirms (Hiatt, 1999) that the use of leaves to measure the concentration of volatile organic compounds requires the knowledge of meteorological conditions, plant type, compound reactivity, and temperature. Seasonal variation, low concentrations for June and July, in concentration of all HMW and some MMW PAHs on leaves of both species confirms Franzaring's (1997) conclusion that ambient air temperature have strong influence on the accumulation of PAHs and that plant–air partition coefficients need to be corrected for temperature dependent sorption. Sunlight as one of the most important factors that affects PAH decay (Kamens et al., 1990) can play an important role in degradation of particle bound PAHs.

4.4. Metals on leaves

For species other than mercury, metals are predominantly condensed on fine particles. Their accumulation can also be attributed primarily to particle-bound deposition. The amounts of all detected metals (with the exception of cadmium) were statistically higher on linden leaves than on pear tree leaves. Cadmium in leaves is correlated to its concentration in soil, whereas all

other metals are found to be superficial contaminants (Sanka et al., 1995; Schuhmacher et al., 1998). The ratio of mean concentrations of metals (except for cadmium) on leaves over the growing season is almost constant and equals two (the same as for particle-bound PAHs). It can be concluded that particle bound deposition is higher on linden leaves than on pear leaves (Table 4).

Various factors could cause the observed differences among species:

1. waxes of different species have different physicochemical properties, which result in a higher retention of atmospheric air pollutants by certain species;
2. presence of sooty molds or other biological entities on the surface of leaves may play an important role in the processes of accumulation and retention of fine atmospheric particles.

5. Conclusions

The results of this research indicate that linden tree leaves possess a higher ability to remove particle-bound PAHs and metals from the atmosphere than pear tree leaves and that this ability is not associated with leaf size or the amount of wax on leaves. The difference in leaf morphology between the two species is not significant enough to cause such a variation in collection of toxins. More research is needed to identify factors that can cause such a difference in the accumulation of fine particles.

Interspecies differences in trapping fine particles by deciduous leaves are an important result of this research. This knowledge can be help in selective tree planting programs to reduce fine particulate matter in the air and, thereby, reduce the danger of human exposure to $PM_{2.5}$.

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