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On the link between biomagnetic monitoring and leaf-deposited dust load of urban trees: Relationships and spatial variability of different particle size fractions

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ABSTRACT

Biomagnetic monitoring of urban tree leaves has proven to be a good estimator of ambient particulate matter. We evaluated its relevancy by determining leaf area normalised weight (mg m^{-2}) and SIRM (A) of leaf-deposited particles within three different size fractions (>10 μm, 3–10 μm and 0.2–3 μm) and the SIRM of the leaf-encapsulated particles. Results showed that throughout the in-leaf season, the trees accumulated on average 747 mg m^{-2} of dust on their leaves, of which 74 mg m^{-2} was within the 0.2–10 μm (~PM_{10}) size range and 40 mg m^{-2} within the 0.2–3 μm (~PM_3) size range. A significant correlation between the SIRM and weight of the surface-deposited particles confirms the potential of biomagnetic monitoring as a proxy for the amount of leaf-deposited particles. Spatial variation of both SIRM and weight throughout the street canyon suggests traffic and wind as key factors for respectively the source and distribution of urban particulates.

1. Introduction

Due to the abundance and variety of emission sources, an ever-increasing number of exposed city dwellers and a complex urban morphology which reduces natural ventilation, air pollution exposure in urban areas attains health-threatening proportions. Considering that more than half of the global population now lives in urban settings (WHO, 2011), a large exposure to urban air pollution can be expected. Currently, more than 85% of the EU's urban population is exposed to atmospheric particulate matter (PM) levels above the 2005 WHO Air Quality Guidelines (EEA, 2013). In terms of potential to harm human health, PM is one of the most important pollutants as it penetrates into sensitive regions of the respiratory system and can lead to health problems and premature mortality (EEA, 2012). Moreover, there currently exists no threshold below which no adverse health effects would be anticipated when exposed to PM (WHO, 2006). Due to the severe health impacts, the atmospheric PM concentration is monitored very closely using telemetric monitoring networks. However, because of its high investment and maintenance costs, low spatial resolution of these networks is achieved. Higher spatial resolution is often achieved using air quality modelling (Berkowicz et al., 1997; Kumar et al., 2011; Nikolova et al., 2011; Vos et al., 2013) or biomonitoring approaches (Matzka and Maher, 1999; Moreno et al., 2003; McIntosh et al., 2007; Hansard et al., 2011; Kardel et al., 2012; Hofman et al., 2013; Rai, 2013). While air quality modelling enables researchers and policy makers to estimate, forecast and calculate scenarios of atmospheric pollutant concentrations, restricted to neither time nor space, continuous evaluation of these models against measurements is vital to produce reliable model results. Accurate air quality assessments, therefore, still rely on measurements, especially in heterogeneous urban environments, where local pollutant levels are known to vary strongly (Nicholas Hewitt, 1991; Briggs et al., 1997; Micallef and Colls, 1998; Mishra et al., 2012). Within the field of biomonitoring, *saturation isothermal remanent magnetisation* (SIRM) of urban tree leaves proves to be a good estimator of traffic derived ambient PM (Kardel et al., 2011, 2012; Rai, 2013). In previous studies, the potential of biomagnetic monitoring was demonstrated both at a local scale, a street canyon in Ghent (Hofman et al., 2013), and an urban scale, throughout the city center of Ghent (Kardel et al., 2012). However, information on the relevancy of the biomagnetic monitoring approach within the different particulate size fractions is scarce. As the health effects of particulate matter are largely determined by its

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particle size, the objectives of this study were (i) to quantify the leaf-deposited particle mass within different size fractions (>10 μm, 3–10 μm and 0.2–3 μm), (ii) to investigate its relationship with the resulting SIRM signal and (iii) to evaluate the spatial variation of both leaf-deposited particle mass and SIRM throughout the street canyon. To our knowledge, this study is the first to present the weight – SIRM relation within different size fractions of leaf-deposited urban dust.

2. Material and methods

2.1. Leaf sampling

A biomagnetic monitoring campaign was conducted in the "*De Villegasstraat*" (51°11′45.75″ N, 4°25′26.46″ E), a typical urban street canyon, in the densely populated city center of Antwerp, Belgium (Fig. 1). Since previous research suggests that differences in leaf SIRM become more pronounced as the growing season proceeds due to a prolonged exposure time (Kardel et al., 2011), leaf samples were collected towards the end of the growing season, i.e. on September 10 and 11, 2012. The street canyon consists of two opposing traffic lanes separated by a row of London plane (*Platanus* × *acerifolia* Willd.) trees and has a typical street canyon geometry with a width (W) of 15 m, a length (L) of 90 m and a height (H) of 10 m. According to the geometry rules described by Vardoulakis et al. (2003), the street canyon can thus be described as a long ($L/H > 7$) regular street canyon (aspect ratio $H/W \approx 1$). The street canyon is characterised by six densely foliated plane trees (T1–T6) with tree crowns reaching from a height of about 4 m (onset of the crown) to 15 m (top of the crown). T1 and T6 were regarded as edge trees since they were positioned at the edges of the street canyon and T2–T5 were regarded as canyon trees since they were positioned inside the street canyon and completely surrounded by other tree crowns and street walls (Fig. 1). All six tree crowns were sampled by means of a boom lift at three heights (3.5, 8.5 and 13.5 m) and four azimuthal directions (NE, NW, SE, SW) around the tree crown. At each of the 72 sampling locations, three samples were collected, with each sample consisting of five fully developed and undamaged leaves. The leaf samples were placed in paper bags, labelled and transported to the laboratory for analysis.

2.2. Filtration and weighing procedure

Laboratory analyses were carried out at the Bioscience Engineering Department and the Laboratory for Bio-organic Mass Spectroscopy of the Department of Pharmaceutical Sciences at the University of Antwerp, Belgium. At the laboratory, each collected leaf sample consisting of five leaves was hand washed using nitrile powder free disposable gloves (VWR) in 800 ml Ultrapure water (<0.1 μS cm^{-1}) (Eurowater, Belgium). The washed leaf area was determined using a Li-3100 area meter (LI-COR Environmental, US). Subsequently, the washing water was stored in an acclimatised dark room at 16 °C awaiting filtration. For the filtration procedure, we used Nuclepore track-etched polycarbonate filter membranes (Whatman, UK). These filter membranes were pre-weighed after 24 h equilibration time at 50% relative humidity (to stabilise the humidity of the hygroscopic filters). Filter mass was determined using a 1 μg precision Mettler MT5 balance (Mettler-Toledo International Inc., Switzerland). To avoid electrostatic charges on the filters, they were passed through an ionizer antistatic system (Mettler-Toledo International Inc., Switzerland) before weighing. Following pre-weighing, the filter membranes were transported to the laboratory in labelled petrislide dishes (Millipore Corp., US) awaiting filtration. The day of filtration analysis, the washing water was shaken up for 4 h at a rotation frequency of 150 rpm using a KS 260 basic shaker (IKA-WERKE GMBH & CO.KG, Germany) in order to resuspend all washed particles. To avoid filter membrane saturation, only 100 ml of the shaken washing water was filtered, using a 47 mm glass filter funnel (GE Healthcare, UK) connected to a vacuum pump (GE Healthcare, UK), over the pre-weighed filter membranes with pore sizes of in succession 10, 3 and 0.2 μm (Fig. 2). For the 0.2 μm pore size, we had to use two filter membranes in order to filter the same quantity (100 ml) to avoid filter saturation. Doing so, we collected three size fractions of surface-deposited particulate matter on the filters: large (>10 μm), coarse (3–10 μm) and fine (0.2–3 μm). Loaded filters were subsequently dried at ambient temperature, equilibrated for 24 h at 50% relative humidity and post-weighed. Consequently, the pre-weight was subtracted from the post-weight to calculate the leaf-deposited particulate mass in every size fraction of each washed leaf sample. Blank filter weights were determined for every size fraction by completing the entire filtration procedure using only Ultrapure water. For each individual filter membrane, the weight of the blank filter was subtracted from the quantified weight of the loaded filter. The resulting weight was finally normalized for filtered volume and washed leaf area. Hereby, we obtained the surface-deposited particle weight of each washed leaf sample within the different considered size fractions (>10 μm, 3–10 μm and 0.2–3 μm). Following this protocol, a total of 1080 leaves were washed and filtered over 648 filters.

2.3. SIRM determination

After the filtration and weighing procedure, each loaded filter membrane was tightly packed using cling film and pressed in a 10 cm^3 plastic container. Following the protocol of Matzka and Maher (1999) and Kardel et al. (2011), these containers were magnetized with a pulsed magnetic field of 1 T using a Molspin pulse magnetiser (Molspin Ltd, UK) and the "Saturated Isothermal Remnant Magnetism"

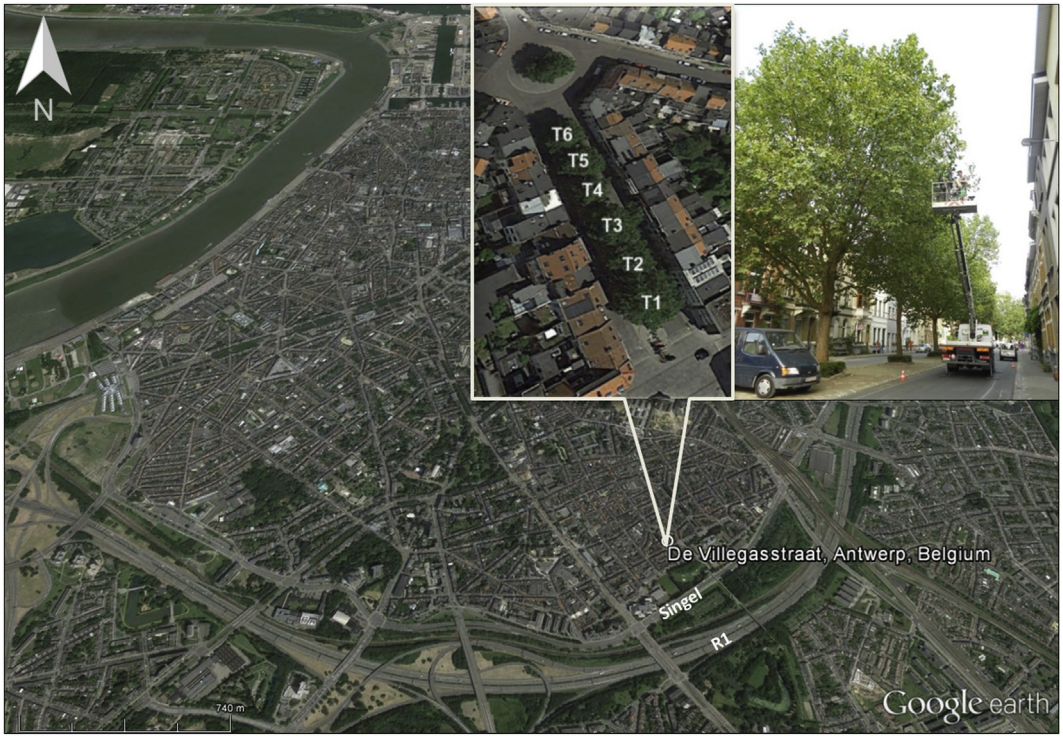

Fig. 1. Location of the street canyon, "Singel" and ring road (R1) in Antwerp (source: Google) with the positions of the considered tree crowns (T1–T6) within the street canyon (middle) and the leaf sampling procedure during the biomonitoring campaign (right).