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On the relation between tree crown morphology and particulate matter deposition on urban tree leaves: A ground-based LiDAR approach

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HIGHLIGHTS

- We quantified leaf-deposited particles gravimetrically within three size fractions.
- Detailed tree crown information was obtained using ground-based LiDAR.
- Leaf-deposited particle mass was compared to LiDAR-based leaf density.
- Increasing leaf density results in lowered leaf-deposition of atmospheric particles.
- The effect leaf density was limited when compared to physical factors.

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ABSTRACT

Urban dwellers often breathe air that does not meet the European and WHO standards. Next to legislative initiatives to lower atmospheric pollutants, much research has been conducted on the potential of urban trees as mitigation tool for atmospheric particles. While leaf-deposited dust has shown to vary significantly throughout single tree crowns, this study evaluated the influence of micro-scale tree crown morphology (leaf density) on the amount of leaf-deposited dust. Using a ground-based LiDAR approach, the three-dimensional tree crown morphology was obtained and compared to gravimetric measurements of leaf-deposited dust within three different size fractions (>10, 3–10 and 0.2–3 μm). To our knowledge, this is the first application of ground-based LiDAR for comparison with gravimetric results of leaf-deposited particulate matter. Overall, an increasing leaf density appears to reduce leaf-deposition of atmospheric particles. This might be explained by a reduced wind velocity, suppressing turbulent deposition of atmospheric particles through impaction. Nevertheless, the effect of tree crown morphology on particulate deposition appears almost negligible (7% AIC decrease) compared to the influence of physical factors like height, azimuth and tree position.

1. Introduction

Despite emission reductions of the main air pollutants in the last decade, air pollution still poses an important threat to public health, the economy and the ecosystems we depend on (EEA, 2013; WHO, 2014). The impacts of air pollution are most strongly felt in urban areas, which currently accommodate over 50% of the global population (WHO, 2010) and in ecosystems, where the pressures of air pollution impairs vegetation growth and harms biodiversity (EEA, 2013). In terms of potential harm to human health, particulate matter (PM) poses the greatest risk, as it penetrates into sensitive regions of the respiratory system and can lead to severe health effects and premature mortality (EEA, 2013). While scientific evidence does not suggest any threshold below which no adverse health effects would be expected when exposed to PM (WHO, 2006), currently more than 85% of the EU's urban population is exposed to PM levels above the 2005 WHO Air Quality Guidelines (EEA, 2013). Moreover, it can be expected that the impact of urban

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Fig. 1. Location of the street canyon with the considered tree crowns (T1–T6) in Antwerp (left, source: Google) and a 3D visualisation of the street canyon based on the LiDAR data (right).

air pollution will only increase further as 70% of the global population will live in cities by 2050 (WHO, 2010).

Source regulations at multiple constitutional levels are indispensable to reduce the cross-boundary impact of air pollution. Nevertheless, growing interest has increased the need for exposure measures that influence atmospheric pollutant concentrations by stimulation of deposition and/or dispersion processes. In this context, research has been conducted on the potential role of urban vegetation as a mitigation tool for atmospheric particulate matter (Beckett et al., 1998; 2000; Yang et al., 2005; Langner, 2007; Litschke and Kuttler, 2008; Sæbø et al., 2012; Maher et al., 2013). Because of its high leaf area relative to the ground area it covers, vegetation (especially trees) can influence local atmospheric particle concentrations both directly, by deposition on its surfaces (Ruijgrok et al., 1997; Sæbø et al., 2012; Terzaghi et al., 2013; Hofman et al., 2014a), and indirectly, by influencing dispersion of PM polluted air (Gromke and Ruck, 2007; Langner, 2007; Vos et al., 2013). Previous research reported on the variation of leaf-deposited dust within single tree crowns and the influence of physical factors like sampling height, wind and street canyon ventilation on the observed variation in dust deposition (Langner, 2007; Hofman et al., 2013, 2014a). This study focusses on variation in leaf-deposited particle mass by evaluating the potential influence of tree crown morphology. Both dispersion and deposition of atmospheric particles are namely influenced by the boundary layer thickness of the air close to the object. Surface roughness increases the boundary layer thickness, hence the momentum of mass transport between the air and the object.

In this study, we tried to establish a relation between the micro-scale leaf density of the tree crown, obtained by detailed ground-based Light Detection and Ranging (LiDAR) measurements, and the weight of leaf-deposited particles within three different size fractions, namely large (>10 μm), coarse (3–10 μm) and fine (0.2–3 μm) particles. The influence of leaf density was tested for two scenarios with respect to the considered leaf sampling locations. We tested for an aerodynamic effect of the surrounding canopy (scenario 1) and the wash-off effect of the upper canopy (scenario 2). In scenario 1, we expect a dense surrounding canopy to reduce wind speed resulting in lower deposition rates as the process of turbulent deposition through impaction is weakened (Lee and Mukund, 1993; Litschke and Kuttler, 2008; Steffens et al., 2012). For scenario 2, we hypothesize that a dense upper canopy might lead to increased wet deposition at the sampling location due to particle wash-off from the upper canopy layers (Urbat et al., 2004; Zhang et al., 2006; Mitchell et al., 2010). To evaluate these scenarios, we quantified the amount of leaf surface-deposited particles gravimetrically within three different size fractions (0.2–3 μm, 3–10 μm and >10 μm) at 72 positions within six urban tree crowns, situated in a street canyon. A LiDAR analysis was conducted to obtain detailed information on the three-dimensional tree crown morphology.

2. Material and methods

A typical urban street canyon was selected in the densely populated city center of Antwerp, Belgium (51°11′45.75″N, 4°25′26.46″E; Fig. 1). The street canyon consists of two opposing traffic lanes separated by a row of London plane (*Platanus x 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) < 1). The street 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). While the street itself is relatively quiet in terms of traffic (50 vehicles h^{-1} (SGS, 2010)), it is located in the vicinity (200 and 400 m) of two busy thoroughfares of Antwerp (*Binnensingel* and *R1*), as can be seen on Fig. 1.