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The influence of roadside vegetation barriers on airborne nanoparticles and pedestrians exposure under varying wind conditions

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HIGHLIGHTS

- Sequential measurements of nanoparticles around a vegetation barrier are made.
- Effect of a vegetation barrier on alleviating the movement of particles is studied.
- Traffic-produced nanoparticles for roadside pedestrian exposure are investigated.
- Vegetation barrier found to reduce PNCs by ~37% during the cross-road winds.
- Presence of vegetation barrier reduced the respiratory deposited doses by ~36%.

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ABSTRACT

Roadside vegetation barriers are used in many urban areas to restrict air and noise pollution from reaching roadside pedestrians, but their effectiveness in limiting the movement of nanoparticles is not yet known. This study investigates the influence of a roadside vegetation barrier on particle number distribution (PND) and concentration (PNC) and associated exposure under different wind directions. Size-resolved particles in the 5–560 nm size range were measured along a busy roadside in Guildford (Surrey, UK) using a fast response differential mobility spectrometer (DMS50). A custom-built solenoid switching system, together with the DMS50, was used to make sequential measurements at the front (L_2), middle (L_3) and back (L_4) of the vegetation barrier; L_1 was in parallel to L_2 at a vegetation-free location. Measured data were divided into the three predominant wind directions: cross-road (NW–SW), cross-footpath (NE–SE) and along-road (NW–NE). The consistency in the shape of PNDs and the corresponding geometric mean diameters at the three sites (L_2, L_3, L_4) indicate an identical removal effect of vegetation barrier for all sizes of particles. Comparison of the PNCs at two parallel locations (with and without the vegetation barrier) showed ~11% higher PNCs ($1.99 \pm 1.77 \times 10^5$ cm^{-3}) at L_2 than those at L_1 during cross-road winds, showing the impeding effect of the vegetation barrier. Such differences were insignificant during the remaining wind directions. Cross-road winds indicate the effect of vegetation barrier; the PNCs were decreased by 14 and 37% at L_3 and L_4, respectively, compared with L_2. During cross-footpath winds, particles were carried away by the wind from the sampling location. Significant decrease in PNCs were consequently seen at L_3 ($1.80 \pm 1.01 \times 10^4$ cm^{-3}) and L_4 ($1.49 \pm 0.91 \times 10^4$ cm^{-3}) compared with L_2 ($6.26 \pm 3.31 \times 10^4$ cm^{-3}). The PNCs at these locations showed modest differences during the cross-footpath and along-road winds. Respiratory deposited doses (RDD) at L_4 were found to be the lowest during all wind directions compared with the L_1–L_3. The vegetation barrier efficiently reduced the RDD by ~36% during cross-road winds. Our results show the mitigation potential of vegetation barriers in limiting near-road nanoparticles exposure and the measured data can facilitate performance evaluation of theoretical models.

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1. Introduction

Recent research has demonstrated an association between the airborne nanoparticles (particles with diameters below 300 nm, which represent the majority of particle number concentrations, PNCs) and adverse effects on human health (Bakand et al., 2012) and urban visibility (Stjern et al., 2011). Airborne nanoparticles also influence the optical properties of coarse particles by depositing on their surfaces due to coagulation and thereby contributing to global radiation balance (Buseck and Adachi, 2008). These adverse effects call for the need to control the emissions of nanoparticles, both at the source and the receptor (Kumar et al., 2011a). Emission mitigation measures in the form of technological improvements, reduction in fuel sulphur content and the Euro 5 and Euro 6 vehicle emission standards (EC, 2008) have reduced the nanoparticle emissions from the vehicles in Europe (Jones et al., 2012). In Europe, road transport emissions contributed over 60% of the total particle number emissions in 2010 (Kumar et al., 2014) and this contribution can be up to 90% along the roadsides in polluted urban environments (Kumar et al., 2010). The assessment of the mitigation potential of the near-road vegetation barriers is therefore important to understand their effectiveness in reducing the exposure of roadside footpath dwellers.

Vegetation barriers along the heavy traffic roadsides can also reduce the traffic-induced pollution from reaching the receptors such as roadside pedestrians. Recent studies have, however, suggested that the presence of vegetation in *street canyons* can enhance the pollutant concentrations by obstructing the flow and trapping the pollutants (Vos et al., 2013). In terms of busy roadsides in *open areas*, vegetation barriers have been found to be beneficial in improving the near-road air quality (Heist et al., 2009; Baldauf et al., 2011). These have been reported to reduce the pollutant concentrations due to enhanced turbulence and initial mixing/dilution (Bowker et al., 2007) and deposition of particles on tree leaves and bark (AdabtOakland, 2013). As highlighted by Baldauf et al. (2011), detailed investigations are needed in order to understand the effectiveness of vegetation barriers under a number of factors such as their long-term assessment during varying meteorological and vegetation state conditions, interactions with traffic-induced pollution, and effectiveness under varying traffic emission and road configuration. The case for nanoparticles is even less encouraging since the efficiency of vegetation barriers in removing them is nearly unknown, and comprehensive modelling and field studies for optimising their design are therefore needed (Baldauf et al., 2013).

A few monitoring and modelling studies have investigated the influence of roadside barriers on various types of pollutants, but

Table 1
Summary of the results of numerous modelling and field studies that have studied the influence of vegetation on nanoparticles.

Author (year)	Site	Size range (nm)	Instrument	Notes
Brantley et al. (2014)	Field measurements	500–10,000	HHPC-6	Diurnal changes in wind direction significantly decreased the pollutant concentrations behind the tree stands, but PNC in the 500–10000 nm size range did not show such reductions.
Hagler et al. (2012)	Field measurements	–	EEPS; CPC; APS; FMPS; SMPS	No reduction in PNCs was observed behind the noise barrier for the upwind cases, while a mean reduction of 47% was observed in other wind directions. Impact of vegetation barrier on PNCs was inconclusive due to the variable meteorological and vegetation conditions.
Baldauf et al. (2008)	Field measurements	–	P-Trak; DMA; CPC; SMPS	Solid noise barrier were found to reduce up to 50% of PNCs. Combination of noise and vegetation barriers was found to reduce the PNCs more efficiently than the noise barrier alone.
This study	Field measurements	5–560	DMS50	Number and size distributions of particles at the front, middle and back of a vegetation barrier assessed. Another sampling location was at vegetation free location. PNCs were found to be reduced by 37% due to the presence of vegetation barrier.
Steffens et al. (2012)	Modelling	12.6–289	SMPS; FMPS	The sensitivity analysis revealed nonlinear increase in deposition based on large leaf area density. Increase in wind speed, reduce particle diffusion, reduce particle concentration for $D_p > 50$ nm but have least effects for $D_p < 50$ nm.
Petroff et al. (2008)	Modelling	–	–	The development of the model was based on aerosol interaction with vegetation canopy. Despite ignoring physical and chemical interaction of aerosol chemistry, the model has resoled aerosol interaction with terrestrial vegetation.
Bowker et al. (2007)	Modelling	20–75	DMA; CPC	QUIC model was applied and compared with the ultrafine particles mobile measurements for all experimental conditions studied.
Lin et al. (2012)	Wind tunnel	12.6–102	SMPS	An analytical model was developed for collection efficiency at tree branches for particles less than 100 nm in diameter. The vegetation drag coefficient is not affected by branch orientation. Brownian diffusion is the major contributor for collection efficiency.
Lin and Khlystov (2011)	Wind tunnel	12.6–102	SMPS	The predictions of filtration theory for removing particles below 100 nm in diameter was found to agree well with the experimental data.
Hwang et al. (2011)	Chamber	300–600	DMA; CPC	Deposition of particles are function of surface roughness of tree leaves (the courser the leaves, higher the removal of particles).

Note: DMA = Differential Mobility Analyser; CPC = Condensation Particle Counter; EEPS = Engine Exhaust Particle Sizer; APS = Aerosol Particle Sizer; FMPS = Fast Mobility Particle Sizer; SMPS = Scanning Mobility Particle Sizer; HHPC-6 = Hand-held particle counter; DMS50 = differential mobility spectrometer.