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Air pollution deposition on a roadside vegetation barrier in a Mediterranean environment: Combined effect of evergreen shrub species and planting density

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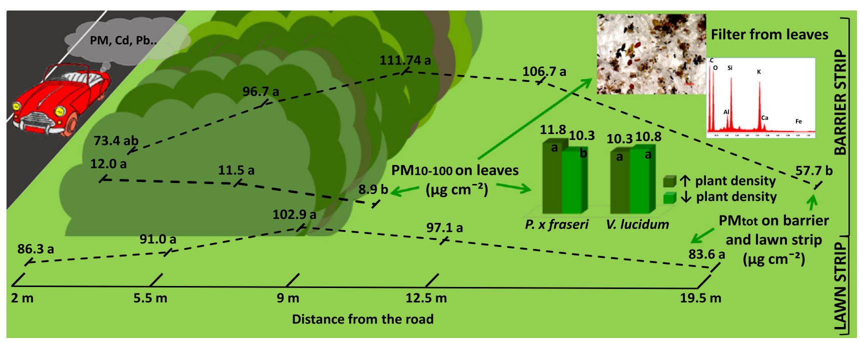
HIGHLIGHTS

- Higher LAI induced higher deposition, while planting density was not a determinant.
- Vegetation barrier changed deposition dynamics in the experimental site.
- Image analysis differentiated between on-leaf PM with different colorations.
- On-leaf PM with different colorations had a different element composition.

GRAPHICAL ABSTRACT



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ABSTRACT

Leaf deposition of PM_{10-100}, $PM_{2.5-10}$, $PM_{0.2-2.5}$ and of 21 elements was investigated in a roadside vegetation barrier formed by i) two evergreen shrub species (*Photinia* × *fraseri*, *Viburnum lucidum*), with ii) two planting densities (0.5, 1.0 plant m^{-2}), at iii) three distances from the road (2.0, 5.5, 9.0 m), at iv) two heights from the ground (1.5, 3.0 m), and on v) three dates (Aug, Sep, Oct).
The presence of black and brown on-leaf PM_{10-100} and their element composition were detected by microscopy and image analysis. Pollutant deposition was also measured using passive samplers at five distances from the road (2.0, 5.5, 9.0, 12.5, 19.5 m) in the area of the barrier and in an adjacent lawn area.
V. lucidum had more $PM_{2.5-10}$ and $PM_{0.2-2.5}$ on leaves than *P.* × *fraseri*, while most elements were higher in *P.* × *fraseri*. Most pollutants decreased at increasing distances from the road and were higher at 1.5 m from the ground compared to 3.0 m.
Higher planting density in *P.* × *fraseri* enhanced the deposition of PM_{10-100} and $PM_{2.5-10,}$ while in *V. lucidum*, the planting density did not affect the depositions.
Black PM_{10-100} decreased a long distance from the road and was entirely composed of carbon and oxygen, which was thus identified as black carbon from fuel combustion.
The vegetation barrier had a higher deposition of most PM fractions at 5.5–12.5 m, while in the lawn area, depositions did not change. At 19.5 m, the PM_{10-100} was 32% lower behind the barrier than in the lawn area. In

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conclusion, the vegetation barrier changed the deposition dynamics of pollutants compared to the lawn area. These results strengthen the role of vegetation barriers and shrub species against air pollution and may offer interesting insights for the use of new road green infrastructures to improve air quality.

1. Introduction

Urban air pollution is a threat for human health, causing nearly seven million premature deaths per year throughout the world (WHO, 2014). Air quality is particularly poor in urban areas because of the high level of emissions by anthropogenic activities (Sawidis et al., 2011). Its negative impact is exacerbated by the fact that 54% of the world's population live in these areas (United Nations, 2014). In Europe, it has been estimated that in 2015, 53% and 82% of urban populations were exposed to higher than WHO's recommendations for daily levels of coarse (PM_{10}) and fine ($PM_{2.5}$) particulate matter (EEA, 2017).

Particulate matter is the most abundant air pollutant, consisting in a mixture of heavy metals, elements, black carbon, soil and other substances (Thurston, 2008; Bell et al., 2011). Improvement of air quality through the reduction of air pollutants is now a widely accepted ecosystem service provided by urban vegetation (Simon et al., 2011; Sæbø et al., 2012; Janhäll, 2015). The dry deposition of solid particles (hereafter, deposition) on leaf surfaces is the basic mechanism of the beneficial action of plants on air quality (Bealey et al., 2007; Nowak et al., 2013).

Leaf deposition is influenced by several factors such as the characteristics of particles (concentration, diameter, composition, etc.), the vegetation (foliage density, porosity to air fluxes, plant height, leaf characteristics, etc.), and the site (proximity of vegetation to pollution source, meteorological conditions etc.) (Fowler et al., 2003; Freer-Smith et al., 2005; Litschke and Kuttler, 2008; Petroff et al., 2008). The deposition of particles with a diameter above 1 μm has been found to increase at higher air particle concentrations and at increasing particle diameters (Fowler et al., 2003).

Increased foliar density leads to higher leaf deposition although very high density can reduce the porosity of the canopy, thus limiting the air flux through the canopy and particle deposition (Tiwary et al., 2005; Baldauf, 2017). Plant height influences air quality in different ways depending on the characteristics of the planting site.

In open areas adjacent to roads, the improvement in air quality is more effective when the canopy is taller than the impacting dust plume from traffic which in proximity to the road can be around two meters (Etyemezian et al., 2003; Etyemezian et al., 2004). On the other hand, in street canyons, trees with a large and thick canopy can also increase air pollution concentrations at the pedestrian level because of a reduction in air pollutant dispersion (Buccolieri et al., 2009).

The proximity of vegetation to the pollution source is another important factor increasing leaf deposition (Pugh et al., 2012) which can limit the dispersion of pollutants to the surrounding environment. Leaf deposition is also influenced by meteorological conditions, for example rainfall can wash off leaf deposition (Nowak et al., 2006) to the ground, thus reducing the possibilities of re-suspension in the atmosphere. High wind speed increases not only deposition but also the re-suspension rate of deposited particles (Beckett et al., 2000; Fowler et al., 2003).

With regard to leaf traits, evergreen plants are able to intercept higher quantities of pollutants compared to deciduous species, especially during the winter season when the concentration of air pollutants is generally higher (Pikridas et al., 2013). Among deciduous species, plants with a longer in-leaf period are usually more effective. Species with smaller leaves and more complex shoot structures are more efficient at capturing PM (Freer-Smith et al., 2005). In addition, the presence of hairs and waxes has been associated with a higher particulate deposition (Sæbø et al., 2012).

Several species, mostly trees native to northern environments (Aničić et al., 2011; Popek et al., 2017), have been investigated in terms of their capacity to remove air pollutants (Dzierzanowski et al., 2011; Sæbø et al., 2012). However there have been few studies on shrub species in southern Europe (Lorenzini et al., 2006; Mori et al., 2016).

Shrubs may represent a sound alternative to trees in reducing air pollution, especially in contexts where tree planting is not possible because of a lack of space or due to law enforcement (e.g. a ban on planting trees in proximity to roads) or because they are detrimental to air quality (Buccolieri et al., 2009; Jeanjean et al., 2017).

Finally, the capacity of plants to reduce air pollution is influenced by the kind of green infrastructure in which the vegetation is located (Abhijith et al., 2017). Roadside vegetation barriers (hereafter, vegetation barriers) are green infrastructures consisting of rows of shrubs and/or trees planted along roads (Abhijith et al., 2017; Baldauf, 2017). They screen people living in neighboring areas from the drift of air pollutants from linear traffic (Al-Dabbous and Kumar, 2014; Lin et al., 2016). The impact of vegetation barriers on air quality has been assessed by experimental (Hagler et al., 2012) and modeling approaches (Morakinyo and Lam, 2016) with contrasting results. While in the experimental study, no clear effects of a roadside vegetation barrier on air quality were found, in the modeling approach, beneficial influences of vegetation barriers were simulated.

Baldauf (2017) reviewed the characteristics of vegetation barriers that can increase the capacity of air pollution mitigation. The height from the ground of vegetation barriers should be higher than the initial dust plume derived from traffic; the recommended value for this parameter is 4–5 m (Baldauf, 2017). The thickness of the vegetation barrier should vary between 5 and 10 m and even more (Neft et al., 2016) depending on the foliar density. An appropriate combination of thickness and foliar density should enable the suspended particles to remain within the vegetation for a sufficient time to permit their removal from the air while limiting air blocking (Neft et al., 2016). The vegetation coverage is also crucial, given that pollutant fluxes can preferentially pass through vegetation gaps (e.g., spaces between plants) instead of through the vegetation barrier (Baldauf, 2017). In such conditions, the effect of the vegetation barriers may be negatively affected. Finally, at least a 50-m-length vegetation barrier is recommended in order to prevent pollutant fluxes from passing laterally to the vegetation instead of passing through it (Baldauf, 2017).

Besides this growing body of research, more investigations are needed to better understand and quantify the effects of roadside barriers on air pollution (Abhijith et al., 2017). There is a lack of experimental data regarding the interaction between vegetation barriers composed of evergreen shrubs, with different planting densities, and air pollutants in the Mediterranean environment. A direct comparison between areas with and without vegetation barriers thus may represents a novel approach.

In a previous study by our research group (Mori et al., 2015a), six evergreen shrub species were characterized for the leaf deposition of PM and 21 elements mainly from traffic in a peri-urban environment during a Mediterranean summer season.

Three out of six species (*Viburnum lucidum* L., *Photinia* × *fraseri* cv. Red Robin Dress and *Elaeagnus* × *ebbingei* L.) were found to be more suitable for air pollution deposition because of the higher growth (in terms of leaf area, leaf area index, plant biomass and more favorable leaf traits) compared with the other species tested.