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Active green wall plant health tolerance to diesel smoke exposure☆

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ABSTRACT

Poor air quality is an emerging world-wide problem, with most urban air pollutants arising from vehicular emissions. As such, localized high pollution environments, such as traffic tunnels pose a significant health risk. Phytoremediation, including the use of active (ventilated) green walls or botanical biofilters, is gaining recognition as a potentially effective method for air pollution control. Research to date has tested the capacity of these systems to remove low levels of pollutants from indoor environments. If botanical biofilters are to be used in highly polluted environments, the plants used in these systems must be resilient, however, this idea has received minimal research. Thus, testing was conducted to assess the hardiness of the vegetated component of a botanical biofilter to simulated street level air pollutant exposure. A range of morphological, physiological, and biochemical tests were conducted on 8 common green wall plant species prior to and post 5-week exposure to highly concentrated diesel fuel combustion effluent; as a pilot study to investigate viability in *in situ* conditions. The results indicated that species within the fig family were the most tolerant species of those assessed. It is likely that species within the fig family can withstand enhanced air pollutant conditions, potentially a result of its leaf morphology and physiology. Other species tested were all moderately tolerant to the pollution treatment. We conclude that most common green wall plant species have the capacity to withstand high pollutant environments, however, extended experimentation is needed to rule out potential long term effects along with potential decreases in filter efficiency from accumulative effects on the substrate.

1. Introduction

Exposure to atmospheric pollutants impacts upon both human and environmental health. In urban environments, many pollutants are concentrated in areas that experience dense vehicular traffic, such as road tunnels and car parks. Vehicular pollutants include a mixture of volatile organic compounds (VOCs), carbon monoxide (CO), oxides of sulphur (SO_x), polycyclic aromatic hydrocarbons (PAHs), particulate matter (PM), oxides of nitrogen (NO_x), ozone (O_3) and carbon dioxide (CO_2) (Thurston, 2008). The health outcomes of continued exposure to these pollutants include asthma, lung cancer and cardiovascular disease from PM, (Perrino, 2010); high level CO_2 can result in chest tightness, throat irritation, coughing and shortness of breath (Erdmann and Apte, 2004); and volatile organic compounds can have carcinogenic, blood and brain toxicity effects (Vaughan et al., 1986; Wallace, 2001; Wolkoff and Nielsen, 2001). To reduce human exposure, various mechanical and physiochemical air filtration devices have been developed to minimize the concentration of air pollutants in indoor environments, however, most of these devices are limited by their lack of ability to successfully remove all types of air pollutants, along with high capital and maintenance costs (Soreanu et al., 2013; Torpy et al., 2015), which precludes them from use in highly polluted outdoor environments.

Outdoor green walls have been identified as a potential nature-based technology for 'future proofing' urban environments, with a range of well recognised ecosystem services; including: improving air quality (Bruse et al., 1999; Rahman et al., 2011; Pugh et al., 2012), increasing urban biodiversity (Lundholm, 2006; Francis and Lorimer, 2011), mitigation of the urban heat island effect (Alexandri and Jones, 2008; Gago et al., 2013; Santamouris, 2014), increasing psychological wellbeing (Theodoridou et al., 2012), reducing building energy demands for cooling and heating (Alexandri and Jones, 2008; Yoshimi and Altan, 2011; Ghaffarian

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Hoseini et al., 2013; Zhang, 2013) and improving stormwater management (Schmidt, 2003). In terms of air quality mitigation properties, passive biofiltration utilizes the simple diffusion of air to green wall components, and is the method used in green roofs, potted plants and biocovers, along with most current green walls (Nikiema et al., 2007; Lundholm et al., 2010; Llewellyn and Dixon, 2011; Veillette et al., 2011). It is well understood that plants and their associated microorganisms can purify the air via passive biological remediation, acting as an air pollutant sink, trapping and converting various pollutants into non-toxic forms (Torpy et al., 2015). This has been demonstrated in laboratory controlled experiments with CO2 and PM, however, the rate at which these pollutants are removed is accelerated when the systems are converted to active (Torpy et al., 2016; Irga et al., 2017). The main advantage of passive phytoremediation however, is the flexibility of installation and cost (Soreanu et al., 2013), however these systems may have limited capacity for remediating high level air pollution, especially PM.

'Active' botanical biofiltration is an emerging technology, which shows promise for overcoming the volumetric capacity limitations of passive biofilters; with the key difference being that active systems contain an additional device to directly supply air to the module, which passive systems lack. Active green wall systems utilize some form of mechanical device to force large volumes of polluted air through the substrate, root zone and foliage. Like passive systems, active botanical biofilters utilize the microbial activity within the biofiltration and plant growth medium to biodegrade volatile organic compounds (Wood et al., 2002; Orwell et al., 2006; Kim et al., 2008), along with the photosynthetic capacity of the plant leaves to remove carbon dioxide (Soreanu et al., 2013). The rates of CO_2 and VOC removal are greater than those of passive systems due to the mechanically assisted transfer of polluted air through active systems (Irga et al., 2017). Further, particulate matter is trapped within the growing medium at a high rate, which is not possible for passive systems (Irga et al., 2017), whilst NO_2 is reduced by both the plant and substrate components of the system (Dover, 2015). The substrate used in botanical biofiltration may also be capable of trapping aerosolised heavy metals (Irga et al., 2017), and CO is removed by the plant leaves and some soil bacteria (Tarran et al., 2007). Active botanical biofiltration therefore has the potential to simultaneously remove most major health-concerning air pollutants.

As with any bioremediation system, the efficiency of active biofilters is dependent on the viability of the biological component (Gàlvez et al., 2012). The types of response and sensitivities of plants to air pollutants vary, with some plants comparatively more tolerant to air pollutants than others. A study by Pandey et al. (2015) suggests that air pollution tolerances should be measured prior to selecting species for passive green wall deployment in street canyons of polluted environments, and the same will apply to active systems. As 'Active' green walls process and are subjected to a higher volume of air, the components of these systems are exposed to higher amounts of pollutants. It is currently unknown whether active botanical biofilters have the capacity to deal with the high level pollutant exposure present in some outdoor applications such as traffic tunnels and street canyons. It is possible that the additional pollutant concentrations at the active zones of these systems may overwhelm their capacity to degrade pollutants, or they may suffer damage. If botanical biofiltration is to be effectively used in highly polluted environments, plant hardiness and pollutant tolerance is likely to be the primary aspect limiting the long-term use and efficiency of these systems. Plant species used for phytoremediation therefore need to be pollutant tolerant to ensure plant health, growth and the removal of pollutants. Thus, testing was conducted to determine the tolerance of several commonly used plant species to high pollution environments, such as traffic tunnels.

The experiments presented here investigated plant health responses to exposure to highly concentrated diesel fuel combustion effluent for a 5-week period, with changes in plant health identified through a range of morphological, biochemical and physiological plant tests, across a range of the most commonly used plant wall species. In doing so, this study aimed to determine the most appropriate plant species for active green wall systems exposed to short term, high pollution loads found in *in situ* street applications.

2. Materials and methods

2.1. Active living wall biofilter design

The current study assessed an active green wall system previously described in Irga et al. (2017). Briefly, the system utilizes assisted aeration by incorporating an axial impeller to both increase pollutant exposure to the substrate and plant rhizosphere, and to allow for particulate matter removal, which is filtered through the substrate. The system is modular, allowing for flexibility in upscale design, with module dimensions of 500 x 500 × 130 mm, with 16 circular compartments for plant insertion. The module is constructed from polyethylene and contains a coconut coir based substrate. When operational, air is drawn into the system, and flows through the plant substrate matrix (25 L total substrate volume), contained within a tight weave high density polyethylene (HDPE) bag – typically used as shade cloth, and returned to the environment. This green wall system has been previously demonstrated to be effective in the removal of VOCs, CO_2 and particulate matter in laboratory trials (Irga et al., 2013, 2017; Torpy et al., 2014, 2015, 2016).

2.2. Plant materials

Eight commonly-used green wall plants were selected for this study, which encompass a range of phenotypic and genotypic variability (Table 1). When not being tested, all plants within their green wall modules were maintained in a glasshouse lined with shade cloth, with an average temperature of 23.7 ± 3.6 °C, relative humidity of 68.1 ± 16.0%, and a maximum mid-day light level of 90 ± 10 μmol.m^{-2}.s^{-1} (4860 ± 54 lux). Plants were allowed to develop for 4 months under glasshouse conditions after planting and prior to testing. All modules were watered once weekly to saturation, as is the normal case for *in situ* use. Module position within the greenhouse was randomized on a weekly basis.

2.3. Characterisation of the air pollutants generated by the test procedure

Hybrid diesel fuel candles were created to facilitate the generation of PM. The candles were 100 mL in volume with 40% retail grade diesel fuel (Shell, Australia), 60% paraffin wax, and housed within a glass beaker (55 mm height x 65 mm diameter). A 60 mm × 7 mm cotton wick was centred in the middle of the candles.

The concentration of pollutants produced by the hybrid diesel fuel candles was estimated using an adapted single pass method, based on the procedure described in Irga et al. (2017). Briefly, the pollutants were generated within a test flow-through duct with sampling devices placed downstream of the pollutant generation. Effluent was drawn through the duct with a vacuum pump with a stable volumetric flow. Total suspended particles (TSP) were recorded with a DustTrack II 8532 optical laser nephelometer (TSI, Shoreview, Minnesota) and fractionated utilising an aerosol particle