Science of the Total Environment 465 (2013) 64–71

Contents lists available at ScienceDirect

Science of the Total Environment

journal homepage: www.elsevier.com/locate/scitotenv

Occasional large emissions of nitrous oxide and methane observed in stormwater biofiltration systems

Samantha P.P. Grover [a,*], Amanda Cohan [a], Hon Sen Chan [a], Stephen J. Livesley [b], Jason Beringer [c,d], Edoardo Daly [a,d]

[a] Department of Civil Engineering, Monash University, Clayton, Victoria, 3800, Australia
[b] Department of Resource Management and Geography, The University of Melbourne, Richmond, Victoria, 3121, Australia
[c] School of Geography and Environmental Science, Monash University, Clayton, Victoria, 3800, Australia
[d] Monash Water for Liveability, Monash University, Clayton, Victoria, 3800, Australia

HIGHLIGHTS

- First study of greenhouse gas fluxes from a stormwater biofilter.
- Observed occasional large emissions of nitrous oxide and methane.
- Biofilter designs with and without a saturated zone were net sinks for methane.
- Carbon dioxide emissions were four times less than those from lawns.

ARTICLE INFO

Article history:
Received 28 September 2012
Received in revised form 7 January 2013
Accepted 9 January 2013
Available online 9 February 2013

Keywords:
Green infrastructure
Water sensitive urban design
Stormwater control measures
Low impact development
Soil greenhouse gas fluxes
Carbon dioxide

ABSTRACT

Designed, green infrastructures are becoming a customary feature of the urban landscape. Sustainable technologies for stormwater management, and biofilters in particular, are increasingly used to reduce stormwater runoff volumes and peaks as well as improve the water quality of runoff discharged into urban water bodies. Although a lot of research has been devoted to these technologies, their effect in terms of greenhouse gas fluxes in urban areas has not been yet investigated. We present the first study aimed at quantifying greenhouse gas fluxes between the soil of stormwater biofilters and the atmosphere. N_2O, CH_4, and CO_2 were measured periodically over a year in two operational vegetated biofiltration cells at Monash University in Melbourne, Australia. One cell had a saturated zone at the bottom, and compost and hardwood mulch added to the sandy loam filter media. The other cell had no saturated zone and was composed of sandy loam. Similar sedges were planted in both cells. The biofilter soil was a small N_2O source and a sink for CH_4 for most measurement events, with occasional large emissions of both N_2O and CH_4 under very wet conditions. Average N_2O fluxes from the cell with the saturated zone were almost five-fold greater (65.6 μg N_2O–N m^{-2} h^{-1}) than from the other cell (13.7 μg N_2O–N m^{-2} h^{-1}), with peaks up to 1100 μg N_2O–N m^{-2} h^{-1}. These N_2O fluxes are of similar magnitude to those measured in other urban soils, but with larger peak emissions. The CH_4 sink strength of the cell with the saturated zone (−3.8 μg CH_4–C m^{-2} h^{-1}) was lower than the other cell (−18.3 μg CH_4–C m^{-2} h^{-1}). Both cells of the biofilter appeared to take up CH_4 at similar rates to other urban lawn systems; however, the biofilter cells displayed occasional large CH_4 emissions following inflow events, which were not seen in other urban systems. CO_2 fluxes increased with soil temperature in both cells, and in the cell without the saturated zone CO_2 fluxes decreased as soil moisture increased. Other studies of CO_2 fluxes from urban soils have found both similar and larger CO_2 emissions than those measured in the biofilter. The results of this study suggest that the greenhouse gas footprint of stormwater treatment warrant consideration in the planning and implementation of engineered green infrastructures.

1. Introduction

With increasing urbanisation rates and the wide recognition of the degrading effect that urban areas have on waterways, many countries are adopting urban green spaces specifically designed to collect and treat stormwater (Davis, 2005; Pataki et al., 2011b). In particular, vegetated biofilters, also known as bioretention systems or raingardens,

* Corresponding author. Tel.: +61 399024664.
E-mail addresses: samantha.grover@monash.edu (S.P.P. Grover), acoh5@student.monash.edu (A. Cohan), hon.sen.chan@gmail.com (H.S. Chan), sjlive@unimelb.edu.au (S.J. Livesley), jason.beringer@monash.edu (J. Beringer), edoardo.daly@monash.edu (E. Daly).

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http://dx.doi.org/10.1016/j.scitotenv.2013.01.035

are well suited for stormwater runoff reduction and treatment applications because of their proven performance and ability to be retrofitted into the urban landscape (e.g., Hatt et al., 2009). Biofilters can be described schematically as trenches filled with layers of different soil media that support selected vegetation species. Stormwater is diverted to the biofilter from a catchment commonly fifty or more times larger than the surface area of the biofilter itself. This stormwater, by slowly moving through the soil media, undergoes series of treatment processes that are physical, chemical, and biological; the treated water is often collected and discharged to receiving water bodies (Hatt et al., 2009). Most of the research on biofilters has focused on the reduction of stormwater runoff volumes and peaks (Davis, 2008; Hunt et al., 2006), and the removal of several types of pollutants of interest to water managers (Bratieres et al., 2008; Hatt et al., 2009; Hunt et al., 2006). Results from laboratory and field studies have been used to improve the design of biofiltration systems towards the aim of increasing pollutant removal performance (Bratieres et al., 2008; Read et al., 2010). Specifically, the presence of a saturated zone at the bottom of the filter media is now often included in the design to enhance the removal of pollutants, especially nitrogen, and to provide a water source for vegetation during dry periods (Blecken et al., 2009; Kim et al., 2003).

Lately, designed urban green spaces have been associated with a gamut of potential benefits to the urban environment, such as mitigation of local temperatures, improved air pollution removal, and carbon sequestration. However, with urban ecology and eco-hydrology still emerging as research disciplines (Kaye et al., 2006; Pataki et al., 2011a), the evidence of these positive effects on the urban environment is not yet experimentally tested and evaluated in different climatic conditions and urban ecosystems (Pataki et al., 2011b). Specifically, there is a lot of uncertainty in the estimation of greenhouse gas (GHG) fluxes between urban soils and the atmosphere. Nitrous oxide (N_2O) emissions of different magnitudes have been observed in several urban lawns and grasslands under different irrigation and fertilisation regimes (Groffman et al., 2009; Kaye et al., 2004; Livesley et al., 2010; Townsend-Small et al., 2011). Likewise, urban lawns and grasslands have been observed to be both sources and sinks of methane (CH_4) depending on irrigation methods and fertilisation regimes as well as vegetation cover (Groffman and Pouyat, 2009; Kaye et al., 2004; Livesley et al., 2010). In comparison with natural soils, Groffman and Pouyat (2009) found that urban soils had reduced CH_4 uptake.

Green spaces designed to collect and treat stormwater, and biofilters in particular, likely host a unique soil biological activity due to the regular inflow of large amounts of water rich in nutrients (Bratieres et al., 2008; Hatt et al., 2009). However, no studies are yet available to provide estimates of GHG fluxes between biofilters and the atmosphere. As such, here we present a first, preliminary experimental study on the exchange of GHGs between the soil of biofilters and the atmosphere. Specifically, our aims are i) to report baseline measurements of N_2O, CH_4 and carbon dioxide (CO_2) fluxes in two working biofiltration cells over the annual range of soil temperature and water content conditions, ii) to compare fluxes of N_2O, CH_4 and CO_2 from two biofiltration cells with different designs, and iii) to report on the observed GHG fluxes from the soil after natural and simulated large inflow events.

2. Methods

2.1. Site description

The study was located at a biofilter that treats stormwater from a multistorey car park at Monash University, Clayton Campus, Australia. The biofilter (Fig. 1) was built in 2006, as described in detail in Hatt et al. (2009). The 45 m^2 biofilter has a catchment of 4500 m^2 and is divided into three separate cells, each 0.7 m deep with a 0.5 m upper layer of filter material over a 0.2 m lower drainage layer. The filter medium in cell I is sandy loam, whilst in cell III is sandy loam (80%), compost (10%) and hardwood mulch (10%). No fertiliser was added to either cell. The vegetation in cells I and III is dominated by sedges, mainly *Carex appressa* and *Lomandra longifolia*. In October 2010, we cut the plants to the same height, thus having approximately the same vegetation cover in these two cells. Cell II was not used in this study because it was recently planted with young trees and the filter medium was sand, thereby making this cell too different from the other two. Perforated pipes embedded within the drainage layers of the cells collect the treated stormwater and discharge it into an adjacent pond. The pipe in cell III has an elbow at its end that generates 0.2 m of saturated zone in the lower drainage layer before water can flow into the pond.

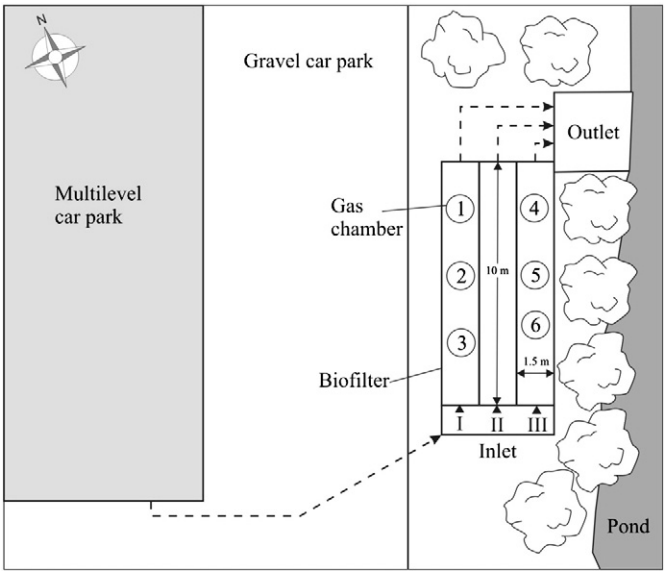

Fig. 1. Schematic representation of the site (not to scale). Stormwater is diverted through an underground pipe from the top level of a car park to the biofilter, and is then delivered to an adjacent pond. The biofilter is divided in three cells (I, II, and III) of equal size; three gas chambers have been installed in cell I and cell III.

2.2. Soil analyses

Soil pH and electrical conductivity (EC; 1:5 soil to distilled water) were measured on soil cores collected in May 2011. Three cores (0–10, 10–20 and 20–30 cm) were taken from adjacent to each chamber. Bulk density was measured in the surface cores (0–10 cm).

Soil nitrate (NO_3^-) and ammonium (NH_4^+) were measured from soil sampled periodically whilst gas fluxes were being measured. Soil cores (0–10 cm) were taken adjacent to each chamber and the three samples from each cell were bulked to form a representative sample. The soil samples were weighed, and subsamples were removed for analysis of gravimetric water content and soil NO_3^- and NH_4^+. Soil samples were extracted with 1 M KCl (1:5, soil:KCl) and shaken for one hour, then filtered (Whatman 42) and frozen prior to analysis of NO_3^- and NH_4^+ on a Technicon™ Auto-analyser. Gravimetric water content was determined through oven drying at 105 °C for 48 h.

2.3. Continuous measurement of soil temperature and soil water content

Soil temperature and soil water content were measured continuously for the duration of the study using PT385 probe (Omega Engineering Inc., New Jersey, USA) and Theta Probes (model ML2x, Delta-T Devices, Cambridge, UK), respectively. Probes were installed at 3, 15 and 30 cm depth in the centre of each cell; two additional probes were installed in each cell at 20 cm depth, one at 2 m from the inlet and one at 2 m from the outlet. Probes were scanned every minute and recorded every 15 min using a DT85 data logger (DataTaker, Australia).