Putting microbes to work: herbicide removal via stormwater biofilters

Mettre les microbes au travail: éliminer les herbicides au moyen de biofiltres pour le traitment des eaux pluviales

Inbar LeviRam[1,2] (inbar.leviram@monash.edu.au),

Moshe Herzberg[1] (herzberg@bgu.ac.il), Amit Gross[1](agross@bgu.ac.il),

Anna Lintern[2](anna.lintern@monash.edu), David McCarthy [2] (davidmccarthy@monash.edu)

[1] Zuckerberg Institute for Water Research, Jacob Blaustein Institutes for Desert Research, Ben-Gurion University of the Negev, Sede Boqer Campus, Israel

[2] Water sensitive Urban design and Environmental and Public Health Microbiology Laboratory (EPHM Lab), Department of Civil Engineering, Monash University, Clayton, Vic, Australia

RÉSUMÉ

Les sources d’eau sont souvent contaminées par des pesticides et des herbicides. Parmi ceux-ci, l'atrazine est le deuxième produit le plus couramment trouvé dans les puits d’eau. Cet herbicide perturbe le système hormonal et peut provoquer le cancer. Pour éliminer efficacement cet herbicide, ainsi que d'autres polluants typiquement présents dans les eaux pluviales, nous avons conçu un prototype de biofiltre de nouvelle génération qui inclut les modifications suivantes: (i) l'incorporation d'une couche confinée de charbon actif granulaire dans le lit des biofiltres, (ii) l’augmentation des microorganismes dégradant l'atrazine et (iii) la sélection d'espèces végétales pouvant renforcer la dégradation de l'atrazine l’activité microbienne. Une étude de laboratoire à long terme utilisant de large colonnes a été conduite sur ce système de nouvelle génération ainsi que sur des biofiltres standards.

ABSTRACT

Water sources are often contaminated with pesticides and herbicides. Of those, the second most commonly found in water wells is atrazine. This herbicide disrupts the hormone system and induces cancer. For achieving effective removal of this herbicide, alongside other typical stormwater pollutants, we designed a prototype of a next-generation stormwater biofilter, which includes the following modifications: (i) incorporation of a confined layer of Granular Activated Carbon into the biofilters' bed (ii) augmentation with atrazine-degrading microorganisms and (iii) selection of plant species with a potential supporting effect for microbial-mediated atrazine degradation. The system was tested in comparison to the standard biofilter design using a long-term laboratory scale biofilter column study.

KEYWORDS

Bioaugmentation, bioremediation, bioretention, micro-pollutants, stormwater

Groundwater and surface water are often highly polluted with widely-used herbicides such as glyphosate, atrazine, and simazine, amongst other pollutants (Perth, Gerritse et al. 2006, U.S Geological survey, 2005). Atrazine is one of the most environmentally prevalent herbicides used globally and the second most commonly found in water wells (Wood A., 2003, Graziano et al. 2006). It is an endocrine-disrupter (alters the hormones and reproduction system) and induces cancer (Hayes et al. 2010, Fan et al. 2007). It has been associated with preterm delivery and intrauterine growth retardation (Chevrier et al., 2011; Gelaye et al., 2016) and is moderately to highly mobile in soils and groundwater (WHO 2011, Moorman et al. 2001).

Stormwater treatment and harvesting are increasingly being used as a way to prevent the input of anthropogenic pollutants into water bodies and to diversify our water sources (Deletic et al, 2014). Of the stormwater control technologies currently being used, one of the most promising is biofilters. Biofilters are natural systems which rely on the soil-plant natural microflora for pollutant removal (Payne et al., 2015).

The main goal of this study is to extend the capacity of stormwater biofiltration technologies that have been designed to date, to treat "traditional water pollutants" to effectively remove herbicides from contaminated stormwater.

While the removal of conventional contaminants such as solids, nutrients, and metals via biofilters is well demonstrated (Bratieres et al., 2008; Fletcher et al., 2007; Hatt et al., 2009), the removal of herbicides by biofiltration has only recently been considered. To date, studies examining herbicide removal are limited, however, preliminary results indicate that current biofilter designs are unable to promote consistent and effective removal of herbicides, e.g. atrazine and simazine were poorly removed (<20%) (Zhang et al. 2012), and traces of herbicides are persistently detected within the treated stormwater water (Deletic et al., 2014).

Herbicides remediation is achievable by a variety of physical, chemical and biological treatment processes (Brown et al., 2004). Of those, microbial remediation is one of the most cost-effective and environmentally-friendly (Elekwachi, 2014), which can potentially be incorporated into biofilters. Microbial-remediation of atrazine has been considered since the 1990s, and different atrazine-degrading bacteria have been isolated from contaminated sites (Struthers et al., 1998; Yanze-Kontchou and Gschwind, 1994). Utilization of atrazine biodegradation in combination with adsorption-desorption mechanisms has been demonstrated as a promising approach for achieving atrazine concentrations lower than the US EPA standards (Shrestha et al., 2003, Herzberg et al., 2003, 2005). This approach uses a reactive substrate with a high surface area that can temporarily bind incoming atrazine as well as support a specialised microbial population (biofilm) capable of subsequently degrading the atrazine to harmless compounds. The adsorption of atrazine to the biofilm carrier appears to be crucial for maintaining its long-term degradation stability (Herzberg et al., 2004). Biofilters can potentially be modified, to provide the micro-ecosystem for atrazine remediation, based on this approach.

In the first stage of the study, we investigated interfacial phenomena of atrazine removal, including biodegradation and adsorption-desorption interactions, using novel quartz crystal microbalance with a dissipation (QCM-D) technique (LeviRam et al., 2019). We monitored in real-time the attachment of atrazine-degrading bacteria to the sensor's surface, atrazine adsorption and degradation, and the consequent proliferation of the irreversibly attached sessile bacteria. Unlike conventional methods, this technique allows monitoring of atrazine biodegradation at the solid-liquid interface, where it is most likely to take place naturally (including biofiltration systems).

In the second stage of the study, the same atrazine removal mechanism, which was investigated in the first stage, was applied to a laboratory-scale biofiltration system. More specifically, we designed a prototype of a next-generation stormwater biofilter for enhanced atrazine removal, which includes the following modifications:

(i) Comprising smart engineering choice for atrazine absorbing media of the biofilters' bed

A confined layer of Granular Activated Carbon was incorporated into the biofilters' bed. It was selected based on essays testing the atrazine adsorption and the biofilm carrier capacities of a representative filter media. The typical biofilter media- sand compared to two filter media alternatives- Granular Activated Carbon and zeolite were characterized: biofilm-coated GAC provided atrazine adsorption capacities in one order of magnitude lower than pristine GAC. Yet, its adsorption capacities were 5-fold higher than biofilm-coated zeolite or biofilm-coated sand as well as their pristine formation. The GAC bed volume was determined according to 15 min Empty Bed Contact Time (EBCT) and consisted 5% w/w of the total biofilter bed.

(ii) Bioaugmentation with an atrazine-degrading bacteria

Inoculum of the previously characterized bacterial strain, Arthrobacter aurescens Phillips TC1 (Strong et al., 2002) was used to enrich biofilters' microbiota. Unlike another microorganism, A. *aurescens* TC1 rapidly consumes atrazine as its source of nitrogen, carbon, and energy. It is metabolically diverse and metabolises a wider range of *s*-triazine compounds than any bacterium previously characterized (Strong et al., 2002). This makes it robust and attractive for removal of triazine herbicides by biofiltration.

(iii) Metagenomic based plant species selection

For selecting plant species with potential for supporting microbial-mediated atrazine degradation; we performed a search of atrazine degrading genes *AtzABCDEF* and *TrzDEFN* (Udikoviç-Koliç et al., 2012), in the biofilter metagenomic database of (Morse et al., 2018). We selected the plant species *Leptospermum continentale*, which has shown the highest copy number of atzF,E genes. This plant species was compared to a typical biofilter plant species: *Carex appressa* and non-vegetated control, in both the standard and prototype next-generation biofilter design.

This promising prototype design of biofiltration utilizing plant-bacteria combination takes one step further toward applications of natural microbial processes, in the battle against water pollution and scarcity. Design optimising such that herbicides are removed, even under extreme operating conditions, is crucial for the protection of the health of receiving waters and public health.

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