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Devenir des micropolluants organiques dans le sol des ouvrages de gestion des eaux pluviales : interaction diversité microbienne et biodégradation

Fate of organic micropollutants in the soil of stormwater management structures: interaction of microbial diversity and biodegradation

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RÉSUMÉ

L'objectif principal de ces travaux est d'étudier le devenir des micropolluants organiques dans les sols de plusieurs ouvrages de gestion des eaux pluviales et d'observer l'interaction entre les populations microbiennes et la biodégradation des micropolluants. Trois sites ont été sélectionnés pour étudier ce devenir avec comme critères de choix des sols : la constitution du sol, la localisation par rapport aux ruissellements, l'âge de l'ouvrage et le couvert végétal. Une caractérisation physico-chimique et biologique des sols a été réalisée suite à plusieurs campagnes d'échantillonnage. Des cinétiques de biodégradation en conditions contrôlées en batch liquides ont ensuite été réalisées afin de comparer les capacités de biodégradation du bisphénol A, du Nonylphénol et de l'Octylphénol des microorganismes autochtones extraits des sols des ouvrages étudiés. Les résultats de ces cinétiques ont montré des efficacités de biodégradation différentes entre les sols d'un même site pour un même micropolluant. Aussi pour les quatre sols du site de Vitry la biodégradation du BPA varie de 20% à 100%. Les pourcentages de biodégradations sont également différents entre les sites (site Dourdan amont : biodégradation de 99% du BPA tandis que la noue du site Compans va biodégrader le BPA à 54% seulement). Ces différences d'efficacités sont à mettre en relation les caractéristiques physico-chimique et microbiologiques des sols étudiés. Nos travaux permettront de mieux comprendre l'évolution dans le temps et dans l'espace de l'efficacité des ouvrages dans la dépollution des eaux pluviales avec comme finalité l'optimisation de leur conception et de leur gestion

ABSTRACT

The main objective of this work is to study the fate of organic micropollutants in the soils of several stormwater management structures and to observe the interaction between microbial populations and the biodegradation of micropollutants. Three sites were selected to study this future with the following soil selection criteria: soil composition, location in relation to runoff, age of the structure and plant cover. A physico-chemical and biological characterization of the soils was carried out following several sampling campaigns. Biodegradation kinetics under controlled conditions in liquid batches were then carried out in order to compare the biodegradation capacities of bisphenol A, nonylphenol and octylphenol of native microorganisms extracted from the soils of the structures studied. The results of these kinetics showed different biodegradation efficiencies between the soils of the same site for the same micropollutant. Also, for the four soils of the Vitry site, the biodegradation of BPA varies from 20% to 100%. The percentages of biodegradation are also different between the sites (upstream Dourdan site: biodegradation of 99% of BPA while the swale of the Compans site will biodegrade only 54% of BPA). These differences in efficiency are to be related to the physico-chemical and microbiological characteristics of the soils studied. Our work will make it possible to better understand the evolution over time and space of the effectiveness of structures in the depollution of rainwater with the aim of optimizing their design and management.

KEYWORDS

Biodegradation, Microorganism, Organic micropollutants, Structure of stormwater management at the source, soils

1 INTRODUCTION

Urban runoff, and especially road runoff, is a vector of diffusion pollution of aquatic environments of major concern (Müller *et al.*, 2020). Lately, nature-based source control measures (SCMs) that allow for on site management of runoff pollutant loads have been promoted. These systems which are based on water percolation through a vegetated substrate allow for filtration and adsorption of micropollutants and have shown good performance for runoff pollution load control (Flanagan *et al.*, 2018). While the physico-chemical functioning of these structures has been widely studied (Tedoldi *et al.*, 2017, Le Fevre *et al.*, 2015), data on the autochthonous microorganisms' impact on biodegradation of organic micropollutants trapped in the soil of these systems is missing. The present work will focus on the link between the microbial diversity of soils of these structures and the fate of micropollutants.

2 MATERIAL AND METHODS

2.1 Study sites and sampling methodology

11 soils, sampled in 5 different SCMs, collecting road runoff from 3 different road sites in Paris conurbation, have been studied. These sites were selected based on previous studies by Tedoldi *et al.* (2017) and Flanagan *et al.* (2018). They all correspond to sites with medium to high potential runoff contamination but differ by the age, soil type, vegetation type and hydrological loading (Table 1).

Table 1. Description of study sites (¹ : based on Tedoldi 2017 and Flanagan *et al.* 2017; ²: after soil stripping, up soil concentration is expected to be similar to the down value)

Site name	Dourdan	Compans			Vitry	
SCM type	Detention/infiltration	Vegetated filter strips		Biofiltration swales		
SCM code	IB_D	VFS1_C	VFS2_C	BFS_C	BFS1_V	BFS2_V
Catchment type	Departmental road (4900 veh/day)	Departmental road (22000 veh/day), high truck traffic			Industrial area service road, high truck traffic	
Inflow of water	Localised piped inflow	Diffuse inflow by surface runoff				
Soil texture	Sandy loam	Clay loam	Sandy loam (filter substrate)		Loam	
Operating time	25 years	1 year (top soil stripping in June 2020)		5 years	15 years	
Vegetation	Spontaneous vegetation			<i>Carex gracilis</i>	Trees	Grasses + spontaneous vegetation
Cu soil content (mg/kg) ¹	Up \approx 160 ; Down \approx 20	Up ² \approx 250 before soil stripping; Down \approx 40		NA	Up \approx 110; Down \approx 50	

Soil samples used in this study were collected during the summer 2021. For the Compans biofiltration swale which is relatively narrow, one composite sample (0-10 cm depth) covering the whole surface of the filter was constituted. For the other SCMs, two composite samples (0-5 cm depth for Vitry and 0-10 cm for Dourdan) were collected: one representative of the area next to the runoff inflow (up) and one representative of the area that is the furthest from the inflow (down). For the Vitry biofiltration swale, two swale portions were studied, one planted with tree and the second with low vegetation density (grasses and spontaneous vegetation).

2.2 Liquid kinetics in batch

Biodegradation kinetics of 3 organic micropollutants commonly found in road runoff (BPA: bisphenol A, 4-NP: nonylphenol and OP: octylphenol), by the microbial communities of the studied SCM soils, were studied in liquid batch reactors and controlled conditions. These reactors contain a BSM culture medium, micropollutants and microorganisms, all incubated at 25°C, in the dark with agitation (150 rpm) for the entire duration of the kinetics. The culture medium used BSM (basal salt medium) is a minimum medium, which contains all the components needed by microorganisms except the carbon source (Peng *et al.*, 2015). The supplemented micropollutants will constitute the only source of carbon. The microorganisms used were autochthonous and extracted from the soil samples. The initial concentrations of the micropollutants used were BPA = 250µg/L, 4-NP = 175µg/L, OP = 75µg/L. Evolution of micropollutant concentrations and microbial activity were followed during 14 days of incubation.

2.3 Physicochemical and biological analyses

Soil samples were analysed for pH, organic matter, particle size distribution, cation exchange capacity and field capacity of soils. The microbial biomass was evaluated based on the most probable number (MPN), the microbial activity was characterized via the enzymatic analysis of several enzymes (FDA, urease and dehydrogenase). Functional diversity was characterized with Ecolog plates while molecular diversity was established by NGS sequencing of bacterial and fungal DNA extracted from soils (Fukuda *et al.*, 2016; Mitchell and Zuccaro, 2006)).

3 RESULTS AND DISCUSSION

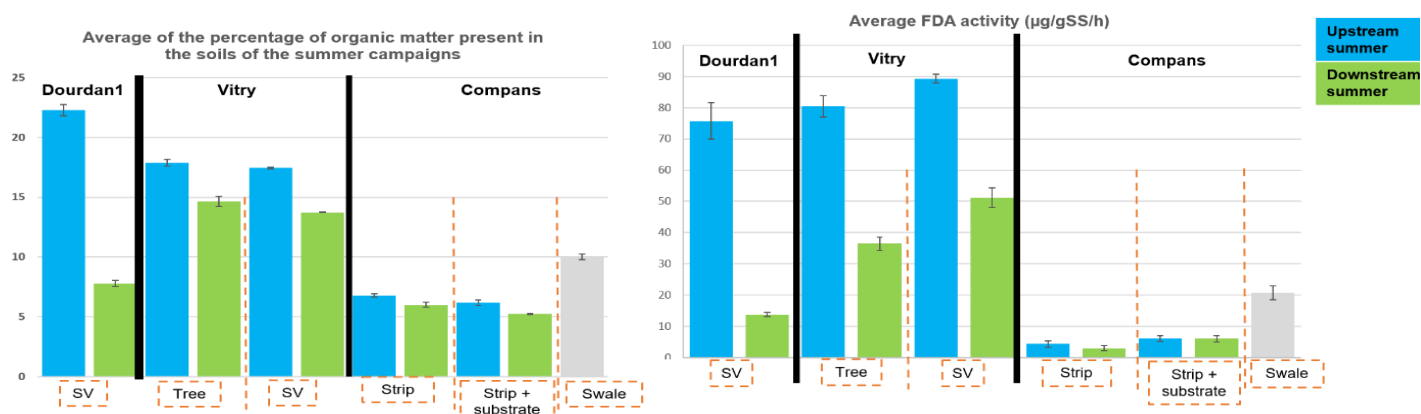
3.1 Biodegradation efficiency of micropollutants during liquid kinetics

Table 2. Percentage of Bisphenol A, 4-Nonylphenol and Octylphenol biodegradation after 14 days of incubation (percentage of biodegradation with more or less the standard deviation):

Site	SCM code	Location	% BPA	% 4-NP	% OP
Compans	VFS1_C	Up	9 +/- 2	0 +/- 1	11 +/- 1
		Down	0 +/- 1	0 +/- 3	20 +/- 6
	VFS2_C	Up	5 +/- 1	0 +/- 3	19 +/- 8
		Down	16 +/- 0	5 +/- 0	17 +/- 5
	BFS_C	/	54 +/- 6	100 +/- 1	100 +/- 0
Vitry	BFS1_V	Up	100 +/- 0	22 +/- 10	44 +/- 18
		Down	20 +/- 1	71 +/- 2	51 +/- 9
	BFS2_V	Up	100 +/- 0	26 +/- 5	21 +/- 10
		Down	100 +/- 0	15 +/- 2	8 +/- 4
Dourdan	IB_D	Up	99 +/- 0	92 +/- 2	95 +/- 5
		Down	98 +/- 1	99 +/- 1	100 +/- 0

As shown in Table 2, biodegradation of the 3 studied micropollutants is observed but with variable efficiency depending on the considered soil. Some sites perform better than others and differences within sites, between up and down samples or between vegetation types, can also be observed. For Compans site, microorganisms extracted from soil of the biofiltration swale (BFS_C) showed a high biodegradation activity for all micropollutant studied comparing to those extracted from the two filter strips soils (VFS1_C and VFS2_C). For Vitry site, the 4 soils biodegrade micropollutant but with specificities: BPA is most completely biodegraded for 3 of the 4 soil samples, while 4-NP and OP show limited biodegradation. The Vitry Up soils were more efficient than the Vitry Down soils. In fact, the soils downstream degrade the micropollutants less and take more time to achieve this biodegradation (result not shown). Our result showed that Dourdan autochthonous microorganisms are the most efficient for biodegrading micropollutants with almost 100% biodegradation of the 3 micropollutants studied. The biodegradation velocity should also be considered: similar percentages of biodegradation after 14 days can be obtained but with very different rate. For some soils the process is very fast with, for example, a significantly biodegradation BPA (40%) from the 3rd day for Dourdan Up, while for BFS2_V Down BPA biodegradation starts only after the 7th day (results not shown).

3.2 Relationship of biodegradation capacities with the physico-chemical and biological soils properties



Figures 1 & 2: Average soil organic matter content and average FDA activity of summer campaigns

Two main physico-chemical and biological characteristics of the soil, namely organic matter (OM) content (Figure 1) and FDA activity (Figure 2), are considered here as explicative parameters of the difference in biodegradation potentials of the studied soils. Dourdan and Vitry soils have high OM content while Compans soils are poor in OM. As a reminder, the Compans filters trips underwent stripping (the top 5 cm of soil were removed) in June 2020 so the soil studied is recent, it has not had time to reconstitute a reserve of organic matter. The FDA activity, which indicates the overall enzymatic activity of the soil, also shows a strong activity for Dourdan and Vitry and a weak activity for Compans. Up and Down differences are also observed, with higher OM content and FDA upstream for all sites.

In our study the soils richest in organic matter and with the highest FDA activity show biodegradation efficiencies that can reach 100%, while the poorest and least active soils are those without biodegradation efficiency. However, MO and FDA are not sufficient to explain all observed differences in biodegradation. BFS_C and IB_D Down have medium OM and FDA values but present the best biodegradation rates. Further analysis of the microbial species involved is needed. It could be that particular microbial species are present specialized in the biodegradation of micropollutants which could explain the high efficiency of these soils despite an intermediate quantity of MO and enzymatic activity.

4 CONCLUSION

To conclude, the biodegradation capacities of micropollutants were shown by the soils tested. However, this soil biodegradation efficiency is different within the soils of the same site and also between the soils of the different sites. These differences are observed both for the final yield and for the rate of biodegradation. There is a correlation between biodegradation and physico-chemical composition as well as microbial activity. In addition to the physico-chemical composition and the microbial activity, there is a last explanatory parameter to take into account which is the microbial diversity.

The study of microbial diversity in progress will be able to help us explain the differences observed. A selection of specialized microbial species to biodegrade micropollutants could be occurred and would explain the different biodegradation efficiencies. Column kinetics will be undertaken on studied soils in order to study the biodegradation of these micropollutants under more real conditions (have all the microbial populations, have the impact of the soil on the bioavailability of micropollutants).

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