Bioretention cell performance in cold climate conditions

Efficacité des zones de biorétention sous conditions de climats froids

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RÉSUMÉ

Cette présentation se focalise sur l'efficacité des systèmes d'infiltration végétalisés pour la gestion des eaux pluviales ("zones de biorétention") sous des conditions de climats froids. Une étude par colonne de sol a démontré que malgré la présence de cycles de gel et dégel, ces zones de biorétention permettent d'infiltrer l'eau et ainsi de contrer en partie le bouchage des pores qui intervient au cours du temps. D'excellents niveaux d'élimination des nitrates et des phosphates injectés dans ces expérimentations ont été observés. Une autre étude sur l'adsorption et la désorption d'un contaminant modèle, le benzotriazole, a permis de prouver que les zones de biorétention permettent de retenir cette molécule, en particulier à des niveaux de concentrations proches de ceux rencontrés sur le terrain, à de faibles températures et hauts niveaux de salinité. En résumé, ces résultats démontrent le maintien de l'éfficacité des zones de biorétention pour infiltrer les eaux pluviales urbaines et retenir les contaminants associés dans des conditions de climats froids.

ABSTRACT

In this presentation, the functioning of bioretention cells in cold climate conditions will be reviewed. Results from column experiments revealed that the effects of freezing and thawing cycles on bioretention soil structure, hydraulic efficiency, and nutrient removal did not negatively affect their infiltration and treatment efficiency. The creation of both larger and more connected pores was directly observed via X-ray tomography of bioretention soil structure, and explained that the infiltration capacity of the system was maintained. In a series of batch tests, the effects of temperature and salinity were investigated on the adsorption and desorption of the anti-freeze chemical benzotriazole. Benzotriazole is frequently detected in urban stormwater runoff, especially in the winter, when temperatures are low, and road salts are applied. The results showed low to moderate adsorption of benzotriazole, with higher retention at the lower temperatures, when benzotriazole is typically at its highest concentrations. Even when desorption was observed, it was low at low benzotriazole concentrations that best represent field conditions. Altogether these results demonstrate the performance of bioretention cells for water infiltration and treatment under cold climate conditions.

KEYWORDS

Bioretention cells, cold climate, freeze-thaw cycles, nutrients, urban runoff

1 INTRODUCTION

Bioretention cells are urban stormwater control systems designed to intercept and infiltrate runoff while removing contaminants. They are often made of a depression in the ground, filled with an engineered sandy soil media, planted with vegetation and covered with mulch. While their efficiency for water infiltration and treatment has been extensively studied in temperate climate (Hunt et al. 2012), their performance under cold climate conditions is less clear (Kratky et al. 2017). In cold climate areas, low temperature, freezing (and thawing), and the application of road salts can affect water infiltration and contaminant removal.

In this presentation, we will review results from two recent studies that aimed at evaluating the effect of cold climate conditions on bioretention cell performance. More specifically, we will first evaluate the effects of freezing and thawing cycles on infiltration, pore distribution, and nitrogen and phosphorus removal via column experiments. Second, we will go over adsorption and desorption results for a model stormwater contaminant, benzotriazole, in bioretention soil and mulch, at various temperature and salinity levels. Benzotriazole was selected because it is a common chemical used in anti-freeze products and regularly detected in urban stormwater runoff, in particular in the winter.

2 MATERIAL AND METHOD

2.1 Effect of freeze-thaw cycles on bioretention performance

Undisturbed bioretention soil cores, 45 cm in length, were collected from a site in Ajax, Ontario (Canada) and placed in experimental columns in the lab for 6 consecutive and replicate injection experiments. Details are provided in Ding et al. (2019). One core was used as a control and left at room temperature for the duration of the experiments. Another core was placed in an environmental chamber and subject to freezing and thawing cycles, with air temperatures cycled between -10°C for 3 days and +10°C for 3 days. The experimental column included vegetation detritus, mulch and snow on top of the column. The experimental column's soil temperature was controlled with a band heater so that only the top 5 cm was allowed to freeze. Each of the six replicate experiments consisted of the injection of an artificial stormwater solution in 0.01 M $CaCl_2$ containing bromide as a water tracer, nitrate, and phosphate, each at 25 mg/L. The solution was held in the column for 3 days before thawing and draining. Water samples were collected from the bottom of the columns (i.e., "drainage effluent" samples) and from the soil pores using Micro Rhizon samplers. The samples were analyzed by ion chromatography, ICP/OES, and a TOC/TN analyzer. At the end of the six experiments, a subsample of the top 5 cm of each column was collected and analyzed by X-ray tomography.

2.2 Effect of temperature and salinity on benzotriazole adsorption and desorption

Composite samples of bioretention soil and mulch were collected from the top 10 cm of a bioretention site located in Vaughan, Ontario (Canada). Details are provided in Rhodes-Dicker and Passeport (2019). The samples were air-dried and sieved prior to use in batch adsorption and desorption isotherm experiments. Briefly, a 0.01 M $CaCl_2$ solution containing benzotriazole was placed in contact with soil or mulch in a tube at different initial concentrations ranging from 2.5 to 50 mg/L. Each concentration level was tested in triplicates. The tubes were shaken for 24 h, centrifuged, and the supernatant removed and replaced with a benzotriazole-free $CaCl_2$ solution for the desorption tests. The 24-h shaking procedure was repeated 3 times. The samples were analysed by HPLC-DAD to quantify benzotriazole. The adsorption and desorption isotherms were modelled by the Freundich and linear models.

3 RESULTS AND DISCUSSION

3.1 Effect of freeze-thaw cycles on bioretention performance

The freeze-thaw cycles resulted in an increase in the drainage properties of the column whereas the infiltration capacity of the control column slightly decreased from the first to the last injection experiments, suggesting that freeze-thaw cycles were able to counteract the effect of clogging. The X-ray tomography analysis revealed different pore size distribution between the two columns. Indeed, in the soil column subject to freezing and thawing cycles, two groups of pores were observed: a group of larger and more connected pores and a group of smaller and more isolated pores compared to the control column. The former was explained by frost expansion during freezing, whereas the latter was due to grain relocation resulting in the merging and shrinking of pores. Interestingly, the total porosity was higher in the control column, at 39.8%, than in the column subject to freezing and thawing, at 32.5%, indicating that the factor porosity alone cannot be used to evaluate whether a higher infiltration can be expected.

Both columns showed extremely high removal of nitrate and phosphate, larger than 96%. Conversely, the water tracer, bromide, was found at concentrations similar to the injected concentrations, thus indicating no significant losses of water. Nitrate concentrations were very low in all samples, but did show slightly higher values in areas where the temperatures were the coldest, e.g., in the top of the experimental column that was subject to freezing and thawing. This temperature-dependence suggests the dominance of microbially-mediated nitrate removal processes. Given that the columns were saturated for 3 days before the onset of drainage, it is likely that denitrification explained the large nitrate concentration decreases observed in both columns. The dominance of microbially-mediated processes was also supported by the production of larger amount of dissolved organic carbon and total dissolved nitrogen – made of organic nitrogen – that both suggest high microbial activity, especially in the control column that remained at room temperature. Total dissolved phosphorus increased over the six injection experiments in the soil porewater of the bioretention soil column subject to freezing and thawing, in particular at the top depths affected by freezing and thawing. However, despite this slight increase over time, the concentrations remained well below 3 mgP/L. In the soil, the solid-phase phosphorus concentration increased after the six injection experiments compared to the initial conditions, especially in the top of the soil. The solid-phase phosphorus concentrations were larger in the control column than in the column subject to freezing and thawing, suggesting that freezing and thawing might have resulted in a decreased potential for P adsorption. However, this effect was very small. Altogether, these results suggest that freeze-thaw cycles did not prevent the bioretention soil from adsorbing phosphorus or denitrifying nitrate.

3.2 Effect of temperature and salinity on benzotriazole adsorption and desorption

The results showed that the adsorption of benzotriazole increased with decreasing temperature. This is explained by a lower solubility of benzotriazole at low temperatures. In addition, the mulch showed larger linear Kd adsorption coefficients than the soil, due to its higher organic content. However, the mulch Koc coefficients, which represent a normalized form of the Kd values to the organic carbon content, were lower. This suggests that the soil's organic matter had functional groups such as proteins more suitable for benzotriazole adsorption than the mulch, which was likely dominated by lignin. The presence of salt only slightly increased the adsorption of benzotriazole on the soil. This is due to a small decrease in benzotriazole solubility, even though this effect was not significant, consistent with what can be expected with polar compounds.

Desorption was the lowest at the lowest benzotriazole concentrations that best represent field concentration values. However, it increased with decreasing temperature, when benzotriazole is most frequently detected due to increased use in winter conditions. The mulch showed more desorption than the soil. The potential for desorption was consistent with the calculated enthalpy of adsorption at -5.6 kJ/mol for the soil and -14 kJ/mol for the mulch. These data suggest the dominance of weak bonds between benzotriazole and the soil and mulch components.

4 CONCLUSIONS

These results helped better understand the fate of contaminants in bioretention cells under cold climate conditions. The findings of these studies showed that bioretention cells can perform well for contaminant removal under low temperature – and freezing – thawing conditions – as well as when road salts are present. While clogging often occurs in bioretention cell over time, the freezing and thawing of water in bioretention soil produced a more connected pore network that might be able to counteract the impact of clogging on infiltration rates, while not preventing the elimination of nitrate and phosphate, when designed specifically for their treatment.

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