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Impact of de-icing salt on treatment and volume reduction of stormwater in bioretention mesocosms in cold climate conditions

Impact des sels de déglacage sur la réduction du volume et le traitement des eaux pluviales des mésocosmes de biorétention en climat froid

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RÉSUMÉ

Les cellules de biorétention (BR) ont démontré de bonnes performances dans la gestion et le traitement des eaux pluviales grâce à plusieurs processus physiques, chimiques et biologiques. Dans des conditions climatiques froides, des différences saisonnières dans ces processus ont été détectées. Cependant, l'effet des conditions climatiques froides (ex : basses températures, dormance des plantes, activité microbienne plus faible) et les polluants spécifiques au climat froid comme les sels de déglacage, sont encore mal documentés. Notre objectif était de déterminer l'impact de l'apport printanier de sels de déglacage lors de la fonte des neiges sur l'hydrologie des BR et le traitement des eaux pluviales, sa persistance dans le temps et la résilience de la végétation des BR au sel appliqué. Nous avons ajouté du NaCl à des concentrations de 0, 250, 1000 et 4000 mg/L sur 12 mésocosmes plantés avec une des 3 espèces suivantes *Iris versicolor*, *Juncus effusus* et *Cornus sericea* et 4 témoins non plantés. Nos résultats n'ont montré aucun effet négatif clair sur la performance générale des BR et sur la croissance des plantes au cours de 4 applications de sel pendant une période de 12 jours et aucun effet persistant. Les plantes ont eu un effet positif sur la performance globale. Une concentration plus élevée de NaCl a amélioré la filtration des métaux, mais a provoqué la libération de cations structurants du sol.

ABSTRACT

Bioretention cells (BR) have shown good performance in stormwater management and treatment through several physical, chemical and biological processes. In cold climate conditions, seasonal differences in these processes have been detected. However, the effect of cold climate conditions (e.g. low temperatures, plant dormancy, lower microbial activity) and cold climate specific pollutants like de-icing salts, have been poorly documented. Our objective was to determine the impact of spring flush of de-icing salt during snow melting period on BR hydrology and stormwater treatment, the persistence of salt effect and resilience of BR vegetation to subjected salt. We applied NaCl in four concentrations (0, 250, 1000 and 4000 mg/L) to 12 planted mesocosms (with one of 3 species *Iris versicolor*, *Juncus effusus* and *Cornus sericea*) and 4 unplanted controls. Our results showed no clear negative effect on the BR general performance and plant growth during 4 salt flush simulations during 12 days period and no persistent effect. Plants had positive effect on the overall performance. Higher NaCl concentration improved metals' filtration, however, also caused release of soil structuring cations.

KEYWORDS

green infrastructure, NaCl, rain garden, salinity, SUDS, vegetation

1 INTRODUCTION

Bioretentions (i.e. rain gardens or biofilters) are increasingly used green stormwater infrastructures worldwide, although the effect of cold climate conditions on their performance is still poorly understood (Kratky et al., 2017; Paus et al., 2015). Due to snowfall and ice cover vast amount of de-icing salts is used on roads and sidewalks to ensure safety. The use of NaCl (the most used de-icing salt) could threaten the functioning of bioretention by negatively affecting the substrate, plants, and microorganisms (Paus et al., 2014). Especially, during the spring flush, when most of the salty snow and ice accumulated during the winter will rapidly melt on the streets.

The objectives of this study were to broaden our understanding on the impact of NaCl on the bioretention's effectiveness, in particular the impact of spring flush on 1) the hydrology and removal of contaminants, 2) on the persistence of the effect after the end of the flush during vegetation period, 3) as well as the resilience of vegetation emerging from dormancy, to this potential stress.

2 MATERIALS AND METHODS

The mesocosm-scale experiment was conducted from spring 2018 until autumn 2020 in the greenhouse at the Institut de recherche en biologie végétale (Montréal, Canada; Fig. 1). Bioretention mesocosms (H78xL35xW35 cm) with gravity flow were filled with 60 cm of a commercial sandy loam (6% organic matter) bioretention media (NATUREAUSOL®) and topped with 3 cm of ramial chipped wood as mulch layer (Fig. 1). A 10 cm layer of granitic gravel (\varnothing 3-7mm) was used as drainage. Rhizotron pipe (\varnothing 7.5cm) was used in each mesocosm for rhizosphere monitoring. From a total of 25 mesocosms of the setup, a sub-set of 16 were used for current salinity experiment. Among the 16 mesocosms, 4 were unplanted controls (UC), and 12 were randomly planted (spring 2018) with one of the three following plant species: *Juncus effusus*, *Cornus sericea*, or *Iris versicolor* (commonly used species in bioretentions in Quebec (Beral et al., 2023)). Once a month, indicators of plant growth and health of aboveground and belowground were measured. At the end of August 2020, all plant parts were harvested, dried and crushed, for chemical analysis.



Figure 1. Mesocosm-size bioretention cell experiment (picture July 2020) and mesocosm design.

The frequency and quantity of stormwater loadings applied mimicked regional average conditions (10-year return data), based on a bioretention area equal to 10% of the collection area (i.e., vegetative period = 10L three loadings/week; dormancy period = 5L one loading/week). At each loading event, the inflow and outflow volumes were measured for water balance calculations. During the acclimatization year 2018, only rainwater was used as an influent. From June 2019 to February 2020 synthetic runoff was used (created from rainwater supplemented with nutrients and contaminants, to replicate the average composition of residential urban runoff (e.g. TOC 49, DOC 35, TN 8.0, TP 0.3, Mg 1.1, K 10.4, Ca 33.3, Fe 5.5, Cr 0.06, Mn 0.06, Ni 0.06, Cu 0.11, Zn 0.55, Pb 0.36 mg/L and Cd 0.04 μ g/L (based on (Duncan, 1999))).

Four salt concentrations (0; 250; 1000; 4000 mg/L) were tested following a Latin square design during 4 loading events, in March 2020. The influent and effluent compositions were analyzed once a month. At each loading, pH, dissolved oxygen, temperature, salinity and electrical conductivity (EC) were measured.

To obtain information about the impact of de-icing salt on the performance of bioretention in cold climate conditions, the average maximum total leaf area per specimen; leaves' and roots' biomass dry weight; average maximum root density; thickness; water quality changes; volume reduction; and exfiltration rate were compared

between different NaCl concentrations, species and time. Statistical analyses were made using R software (ver. 4.1.2).

3 RESULTS AND CONCLUSIONS

Overall, regardless of the de-icing salt concentration applied during spring flushes, the plants showed no growth defects, deficiencies, or signs of NaCl-related stress after they emerged from dormancy.

In general, spring salt flushes did not impact the evapotranspiration and exfiltration rate and therefore, the stormwater volume and peak flow reduction by the BRs. The differences between mesocosm were not detected during salt application (e.g. average evapotranspiration rate only 0.5 mm/d). However, during vegetation period, the presence of plants significantly increased stormwater volume reduction.

During salt application and after the flushes, salt increased metals' retention (more with higher salinity level) and the average trace elements removal was at least 82% for Cr, Mn, Ni, Pb, Zn, and 66% and 43% for Cu and Fe, respectively (Fig. 2). On the contrary, the main soil structuring cations Ca and Mg (Fig. 2), as well as Na, were released from planted mesocosms on average -88%, -477%, -205%, respectively.

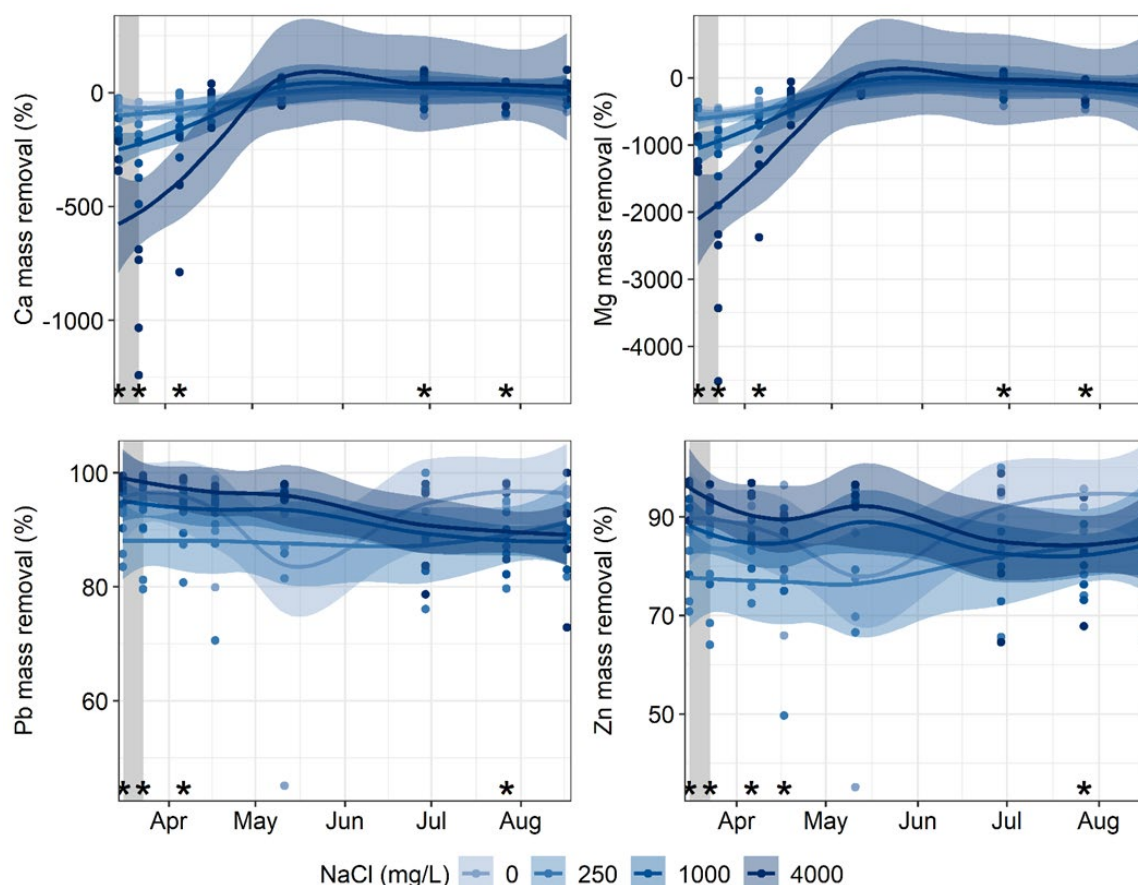


Figure 2. Mass changes (%) of different water parameters in function of NaCl concentration applied (blue gradient) during flush period (marked by the vertical grey band) (number of sampling events = 8). The symbol * on graphs indicate significant differences (set at $p < 0.05$) between NaCl treatment, tested for each date since NaCl*Date interaction was significant in the full LMM.

The nutrient removal was consistently higher in planted mesocosms (at least 88% TP, 95% PO₄, 72% TN, 74% NO₃, 94% NH₄, 72% K) than in unplanted controls (52%, 71%, 12%, -142%, 86%, 0%, respectively).

Furthermore, higher NaCl concentrations resulted with more intense and persistent effect on performance. Other studies have shown that long-term exposure to salt has resulted in colloids dispersion, reduced hydraulic conductivity and soil water capacity, and ultimately limited water bioavailability and transpiration by plants

(Denich et al., 2013). All tested species were resilient to the salt flushes occurring during their dormancy, regardless of the NaCl concentration applied. This suggests, that applied salt flushes were not consequential enough to affect plants that are still dormant. However, salt effect could also vary depending on exposure time and therefore, further long-term studies are necessary for detecting the impact of de-icing salt on the performance of BR.

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