The effect of zeolite amendments on nitrogen leaching from extensive sedum green roofs

Effet de la zéolite sur le lessivage de l'azote provenant de toitures végétalisées extensives

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RÉSUMÉ

Trente-deux toitures végétalisées extensives pilotes ont été construites en Juillet 2017 à Stevens Institute of Technology (New Jersey, Etats Unis) afin d'évaluer l'effet de la composition du substrat sur la qualité des eaux de ruissellement. L'effet de la zéolite, mélangée au substrat et/ou en tant que barrière perméable réactive (BPR) avale, sur le relargage de l'azote est étudié en parallèle de substrats conventionnels de toitures végétalisées extensives. La précipitation, les volumes de ruissellement et les concentrations moyennes (CM) des différentes formes d'azote contenues dans les ruissellements provenant de toitures végétalisées et conventionnelles (sans végétation) sont actuellement mesurés. Jusqu'à présent, les CM et masses d'azote total exportées des toitures végétalisées sont statistiquement plus élevées que pour les toitures conventionnelles. Les CM d'azote inorganique ne sont pas significativement différentes cependant la rétention des eaux de ruissellement par les toitures végétalisées implique une réduction des masses d'azote inorganique exportés par rapport aux toitures conventionnelles. Les CM ou masse de NOx pour des toitures végétalisées sont significativement plus élevées que celles des toitures conventionnelles. Entre les différentes configurations de toitures végétalisées, la zéolite, mélangée au substrat ou en BRP, diminue le relargages d'azote, cependant ces impacts pourraient ne pas être statistiquement significatifs. La BPR a pour avantages d'être un moyen facile d'amélioration de toitures végétalisées existantes et, à plus long terme, peut être remplacée sans endommager la végétation.

ABSTRACT

Thirty-two pilot scale extensive green roofs were established in July 2017 at Stevens Institute of Technology (New Jersey, USA) to evaluate the effects of substrate composition on runoff quality. The effect of zeolite on nitrogen leaching, as either a mixed-in component in the substrate and/or as a downstream permeable reactive barrier (PRB), is being investigated in combination with typical extensive green roof substrates. Ongoing data collection includes precipitation, runoff volumes and event mean concentrations (EMCs) of nitrogen compounds in runoff from green roofs and ungreened roofs surfaces. To date, EMCs and mass load of total nitrogen in green roofs are statistically greater than ungreened roofs. Inorganic nitrogen EMCs are not significantly different, but runoff retention renders the green roof a sink of inorganic nitrogen on mass basis. Either EMC or mass load of NO_x in green roofs are significantly greater than that in ungreened roofs. Between green roof configurations, both mixed-in and PRB amendments mitigate nitrogen leaching, though these impacts may not be statistically significant. The PRB amendment provides advantages of being easier to retrofit to existing green roofs and replaced without disturbing the vegetation for long-term operation.

KEYWORDS

Discharge quality, green roof, inorganic nitrogen, total nitrogen, zeolite amendment.

1 INTRODUCTION

Green roofs are an increasingly important Green Infrastructure (GI) technology designed to reduce demand on over-taxed urban drainage systems. While green roofs substantially reduce the quantity of runoff, literature indicates that green roofs may substantially elevate the concentrations of priority stormwater pollutants, nitrogen and phosphorus, compared to ground level runoff, i.e., solving one problem may create another (Barr et al., 2017; Berndtsson, 2010; Fassman-Beck and Simcock 2013; Teemusk et al., 2011). Elevated nutrients in green roof discharge could contribute to eutrophication in downstream aquatic environments. The magnitude of the problem, and the mechanisms of nutrient cycling, retention, and discharge through a green roof to the environment is unclear.

The substrate (growing media) layer and plants are the two major components that differentiate a green roof from a conventional roof, and they are the potential factors causing nutrient leaching. Theoretically, a green roof can act as a pollutant sink due to media's intrinsic property of rainfall retention and pollutant adsorption. However, studies have reported inconsistent results, suggesting that a green roof may act as pollutant source for some forms of nutrients (Barr, 2017; Fassman-Beck and Simcock 2013; Teemusk, 2011). Elsewhere, studies have suggested that nutrient leaching diminishes as a green roof matures, and the system stabilizes (Speak et al., 2014; Berndtsson, 2010).

In the field study presented herein, measures to limit nitrogen leaching from a green roof are being investigated with specific emphasis on substrate materials and supplemental downstream treatment. Pumice or expanded clay, and compost are used as typical substrate materials in this study, while zeolite is either mixed into the typical substrate or separately implemented in a downstream permeable reactive barrier (PRB). The PRB acts as a filter through which green roof leachates pass. The overall objective of this paper is to evaluate the effects of typical green roof configuration (no amendment), downstream PRB and mixed-in zeolite on nitrogen compounds green roof discharge.

2 MATERIALS AND METHOD

The field site consists of 32 extensive pilot scale green roofs (trays) placed on the roof of a 3-storey building on the Stevens Institute of Technology campus in New Jersey, USA. Each tray has the inner dimensions 81.3 x 121.9 x 15.2 cm (WLH). The trays drain at ~2% towards a covered gutter (Figure 1). The inside of the trays is divided into two compartments: an area of 0.91 m^2 filled with the substrate mix at 127 mm depth and a downstream area of 0.08 m^2 allocated for PRB. Discharge occurs via a typical green roof drainage layer underneath the media. The trays were planted with 4 varieties of industry-standard commercial sedum plug plants at a density of 46.5 plugs/m^2. An irrigation system waters plants after four days of dry weather in summer. 20L buckets secured beneath the gutter collect discharge from the trays.

Figure 1 North Building green roof experiments (left) and tray assembly (right)

This study reports results from 9 replicated configurations in the experimental system occupying 32 trays. There are two base engineered media mixes, replicating industry-typical media (pumice and expanded clay as light-weight aggregates plus compost), but without using proprietary materials. In configurations amended with zeolite, the material was either mixed into substrate or filled up the PRB. The different configurations consist of various volumetric combinations of light-weight aggregate, compost and/or zeolite. Two trays are constructed as "ungreened" conventional roofs, to serve as a baseline for comparison.

Runoff from each tray is captured in 20L buckets. The storm discharge samples are analyzed for total nitrogen (TN), TKN and nitrogen oxides (NOx) (Hach Method 10242); and total inorganic nitrogen (Hach Method 10021). The site was established in Aug-Sept 2017. Sampling began within one month of construction of the experimental systems. Loss on ignition tests to measure substrate organic content were conducted on Oct. 2017 and Oct. 2018 respectively according to the Standard Methods procedure 2540 G (Clesceri et al. 1998).

Neither EMCs nor mass load of total nitrogen, inorganic nitrogen and NO_x are normally or lognormally distributed. Thus, the data are processed using descriptive statistics such as median and inter-quartile range and non-parametric statistical analysis (Kruskal-Wallis Test).

3 RESULTS AND FUTURE ANALYSIS

To date, 16 events have been sampled for water quality analysis. Statistical analysis shows that both the EMCs and mass of load of TN and NOx are significantly greater in green roofs than reference roofs (Figure 2). The EMCs of total inorganic nitrogen in reference roof runoff is not significantly different from the green roof runoff, however, the mass load of total inorganic nitrogen from reference roofs is significant greater. The data confirm that the green roofs' engineered growing media itself is a pollutant source for total nitrogen and NOx in terms of EMCs, whereas it is a sink for total inorganic nitrogen (Figure 2). There are two possible hypotheses that can be proposed from the data: the primary form of inorganic nitrogen from reference roofs is ammonium; through complex nitrogen cycling (ammonification, assimilation and nitrification) by plants and living organisms in the substrate, excessive NOx is discharged.

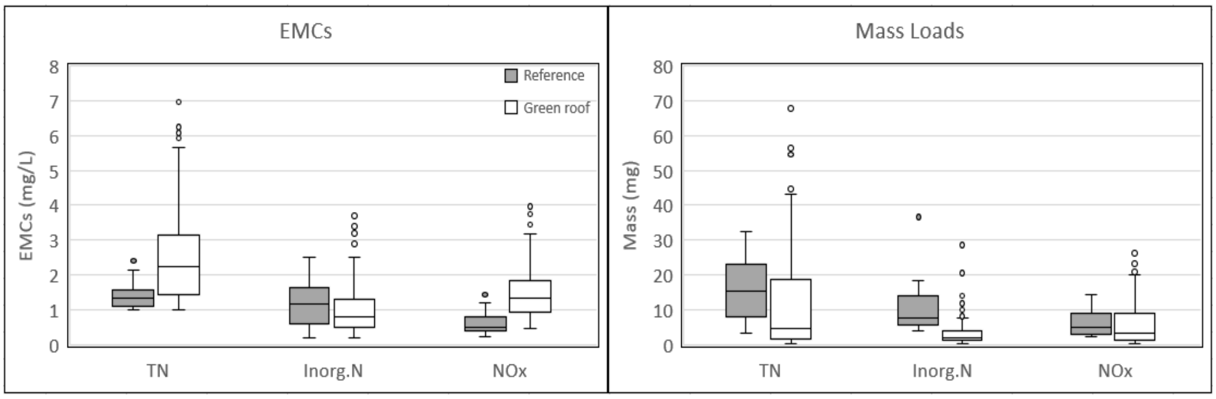

Figure 2 EMCs (left) and mass loads (right) of total nitrogen, inorganic nitrogen and NO_x from pilot scale ungreened reference roofs and green roofs.

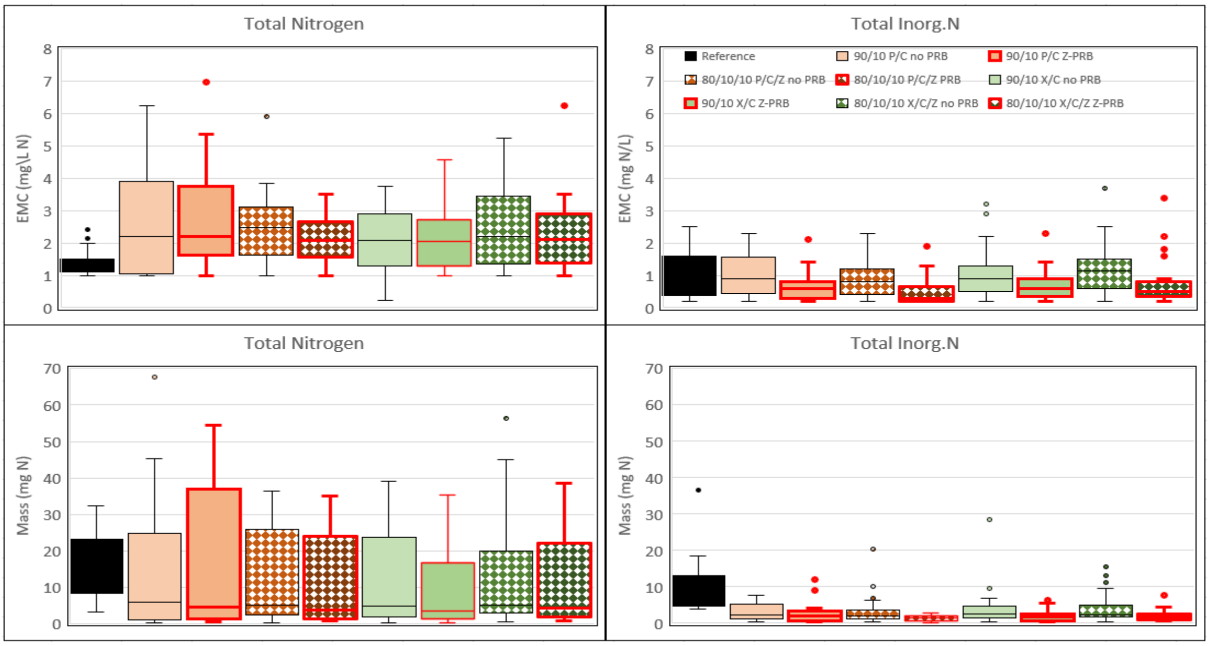

Figure 3 The EMCs (top) and mass loads (bottom) of total nitrogen and inorganic nitrogen from reference and green roofs. Legend indicates volumetric ratios of substrate components pumice (P), expanded clay (X), compost (C), and zeolite (Z).

The median TN EMC and mass discharge among each green roof configuration is similar (Figure 3). The only statistically significant differences were observed in inorganic nitrogen EMC amongst different green roof configurations. The configuration of pumice/compost/zeolite with a zeolite PRB (80%/10%/10%) discharges significantly less inorganic nitrogen EMC than other green roof configurations. While a 10% zeolite addition as either mixed-in amendment or as a PRB decreases inorganic nitrogen leaching, doubling the volume in the combination of a mixed-in addition and PRB maximizes the benefit, amongst configurations tested.

Over the one-year period of monitoring, none of the experimental systems demonstrated a seasonal variation of TN or inorganic nitrogen EMC. Inorganic nitrogen EMCs is highly variable between events, likely because its source is suspected to be atmospheric deposition. For green roofs without a PRB, a slightly linear decreasing overall trend in TN EMCs is observed, whereas the systems with a PRB show more consistent results. Results suggest that the PRB configuration more or less captures TN. The results from loss on ignition tests show that organic content in the substrate barely changed over a year.

On-going work includes statistical analysis and multiple comparisons of specific nitrogen forms among each green roof configuration. Nitrogen leaching mitigation performance for each green roof configuration will be evaluated. Whether green roof system is stabilized based on substrate organic content and nutrient discharge will be further investigated.

4 CONCLUSION

In pilot-scale experimental green roof system planted with sedums in New Jersey, various substrate combinations and a PRB configuration, EMCs of TN and NO_x in green roof discharge are significantly greater than the reference roof. The results are not consistent with some previous studies. Total nitrogen and nitrate concentration of green roof have been either observed higher than (Teemusk, 2011; Barr, 2017) or lower than (Berndtsson, 2009) that in precipitation or a control roof, though the difference may not be statistically significant (Gregiore, 2011; Fassman-Beck, 2013). Mass load studies are consistent with this study that green roof functioned as a sink for TN (Carpenter, 2016; Rowe, 2011), NO_x (Gregiore, 2011) and inorganic nitrogen. The green roof configurations in this study, mitigate inorganic nitrogen mass discharges in into environment. This is important because inorganic nitrogen is available for plant uptake, potentially contributing to eutrophication. Between green roof configurations, the combination of mixed-in and PRB amendments in pumice or expanded clay-based substrates mitigate both EMCs and mass of inorganic nitrogen leaching. For total nitrogen and inorganic nitrogen EMCs, zeolite PRB amendments are slightly, but not significantly, more efficient than mixed-in zeolite amendments. Overall, zeolite as an amendment material, provides a nitrogen-leaching mitigating function, for particularly inorganic nitrogen reduction. From a design standpoint, the PRB amendment provides an advantage of an easier retrofit to existing green roofs and can be replaced without disturbing the vegetation for long-term operation.

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