Green Roof Ecosystem Services and Disservices: Nutrient and Metal Cycling

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Introduction

Water resource issues in Cincinnati, OH, are issues common to many cities of the region: frequent pollution release to rivers during storm events due to an overburdened combined sewer-stormwater system, and nutrient loading from urban and agricultural watersheds causing surface water eutrophication. Green (vegetated) roofs are a component of green infrastructure gaining traction in US cities, with known benefits including stormwater retention and improved energy efficiency. Currently however, little is known about the potential for green roofs to provide direct nutrient removal/retention for the water passing through them.

Our group carries out interdisciplinary research on the biogeochemical function of green roofs, including services like nutrient retention/removal and carbon sequestration, but also potential dis-services like nutrient and metal leaching, and greenhouse gas emissions. Here we present results on nutrient and metal concentrations in runoff from green roofs.

Fig. 1. Sloped green roof at Civic Garden Center of Greater Cincinnati, used for monitoring of runoff water quality on full-scale roof.

Fig. 2. Experimental plots at Cincinnati Center for Field Studies, used for monitoring runoff water quality at plot-scale.

Methods

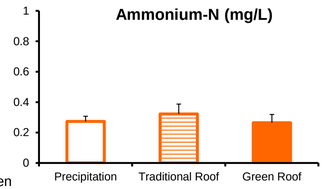
We use a combination of experimental test roof plots, monitoring of existing roofs, and modeling to upscale results and put them in the context of city water resources. In this study we present results from three studies:

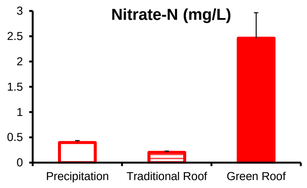
1. **Monitoring of runoff water quality** from a 50 m^2 sloped extensive green roof from all rain events for 18 months (N=71), together with a shingled “traditional roof” control and incoming precipitation water quality.
2. Runoff water quality from twenty-four small (1’ x 2’) **plot-scale green roof microcosms** from four rain events during Aug-Sept 2011. Treatments including varying plant types but all are averaged together here.
3. **Leachate** water quality from common green roof **growth medium components** used in the plot-scale experiments including: sand, heat-expanded shale, heat-expanded clay, mushroom compost, and Canadian peat.

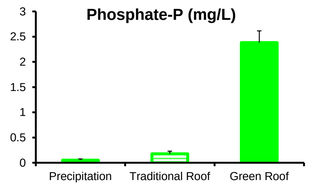
Results 1: Nutrients in runoff from full-scale green roof (average of 71 rain events)

Bottom Line: Ammonium concentrations were unchanged, but both Nitrate and Phosphate were leached out of the full-scale green roof at high concentrations during rain events.

Fig. 3. Runoff water quality measurements taken at downspout of traditional shingled roof (left) and green roof (right).







Results 2: Nutrients in runoff from plot-scale experiment (average of 24 plots during 4 rain events)

Bottom Line: In the small-scale green roof plots, Nitrate concentrations in runoff were reduced but Phosphate and particularly Ammonium leached out during rain events..

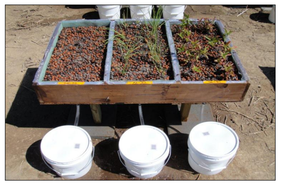
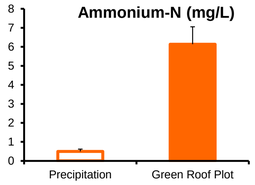
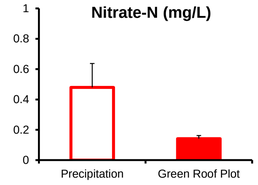
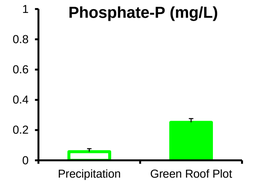


Fig. 4. Runoff water quality measurements taken from buckets draining plots after each rain event.



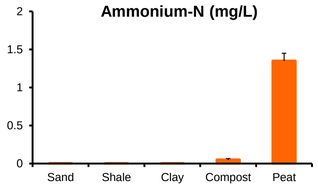


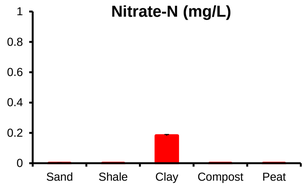


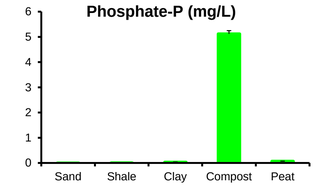
Results 3: Nutrients in leachate from individual growth medium components

Bottom Line: In laboratory experiments, different growth medium components were responsible for leaching out different nutrients: Peat for Ammonium and Compost for Phosphate. Nitrate leaching was minimal.

Fig. 5. Individual growth medium components were leached (10g substrate in 100mL deionized water) in the lab.







In the Pipeline: Newly Installed Continuous Flow Measurements

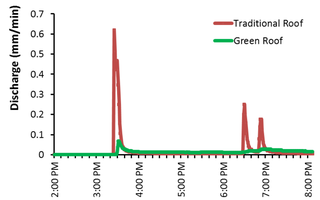


Fig. 6. Continuous runoff water quantity measurements have recently been added and will be used to calculate input/output budgets for all water quality parameters for green roof and control roof. Figure shows installation (left), thelmar weir with pressure transducer (middle) and sample data from a rain event (right).

Results 4: Water quality of runoff: Metals, salts and organic carbon

Analyte	Units	Precipitation	Traditional Roof Runoff	Green Roof Runoff
pH	pH units	5.7	6.5	7.0
Conductivity	µS/cm	22	53	232
DOC	mg/L	5	12	34
Ca	mg/L	1.1	4.5	24.8
K	mg/L	0.6	2.3	10.1
Mg	mg/L	0.2	0.6	4.6
Na	mg/L	0.3	0.4	2.3
Ag	µg/L	4.7	4.1	4.1
Al	µg/L	bd	3.9	32.9
Cu	µg/L	bd	194.3	15.0
Fe	µg/L	bd	67.0	61.6
Mn	µg/L	5.8	18.7	5.2
Zn	µg/L	27.2	372.9	562.9

Average concentration values for precipitation, traditional roof runoff and green roof runoff at the full-scale roof (N=71 rain events during 18 months) for water quality parameters. See “Results 1” panel for values for inorganic nutrients. DOC = dissolved organic carbon; bd = below detection limit. Green roof values are shown in **red** when significantly higher, **blue** when significantly lower than traditional roof values for the given parameter (ANOVA, α=0.05).

Summary

- Green roofs released inorganic nitrogen and very high levels of inorganic phosphorus (a disservice), as well as dissolved organic carbon and common ions, while reducing some trace metals like Copper and Manganese.
- Different growth medium components were responsible for the high P and N concentrations in runoff from our plot-scale experiments. The direct impact of green roofs on downstream water quality is thus highly variable, in large part related to variations in green roof substrate.
- Understanding and managing the impacts of green roofs on urban water resources requires a comprehensive evaluation of the relationship between green roof composition and biogeochemical function. We recommend exploring use of growth medium with a more balanced nutrient stoichiometry, to provide a means of both sustaining healthy plant growth and minimizing any negative water quality effects.

Acknowledgements

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