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## Biochar granulation and vegetation improve leachate water quality from a green roof substrate

### La granulation de biochar et la végétation améliorent la qualité de l'eau de lixiviation d'un substrat de toit vert

Wenxi Liao<sup>a,1</sup>, Jennifer Drake<sup>b,2</sup>, Sean C. Thomas<sup>a,3</sup>

<sup>a</sup>Institute of Forestry and Conservation, John H Daniels Faculty of Architecture Landscape and Design, University of Toronto, 33 Willcocks St., Toronto, ON, M5S 3B3, Canada. <sup>b</sup>Department of Civil and Mineral Engineering, University of Toronto, 35 St. George St., Toronto, ON, M5S 1A4, Canada.

<sup>1</sup>wenxi.liao@mail.utoronto.ca; <sup>2</sup>jenn.drake@utoronto.ca;

<sup>3</sup>sc.thomas@utoronto.ca

#### RÉSUMÉ

Le biochar a été suggéré comme additif de substrat idéal sur les toits verts en raison de ses propriétés favorables. Cependant, les biochars non transformés sont sensibles à l'érosion éolienne et hydrique. La granulation de biochar pourrait atténuer la perte d'érosion du biochar tout en améliorant la qualité de l'eau de décharge, mais les effets du biochar granulé sur la qualité du lixiviat n'ont pas été examinés. La végétation influence également la qualité des décharges d'eaux, mais les performances des plantes varient selon les types de biochar. Dans cette étude, nous avons étudié les effets du type de biochar et de la végétation sur la qualité du lixiviat d'un substrat de toit vert. Nous avons constaté que l'amendement des biochars granulés améliorait la qualité du lixiviat intégré, probablement en raison des effets combinés d'une forte capacité de sorption et d'une amélioration des performances des plantes. En revanche, l'ajout de biochar non traité réduit mieux le volume de lixiviat que l'ajout de biochar granulé, résultant peut-être de la capacité de rétention d'eau plus élevée du premier. La présence de végétation a amélioré la qualité du lixiviat et réduit le volume de lixiviat, probablement en raison de l'absorption continue d'éléments nutritifs par les plantes et de l'interception de l'eau. Nous concluons que les biochars granulés ont un grand potentiel pour améliorer la qualité des effluents rejetés des toits verts.

#### ABSTRACT

Biochar has been suggested as an ideal substrate additive on green roofs due to its favourable properties. However, unprocessed biochars are susceptible to wind and water erosion. Biochar granulation could alleviate biochar erosion loss while improving discharge water quality, yet effects of granulated biochar on leachate quality have not been examined. Vegetation also influences discharge quality, but plant performance varies with biochar types. In this study, we investigated effects of biochar type and vegetation on leachate quality from a green roof substrate. We found that amendment of granulated biochars improved integrated leachate quality, likely due to the combined effects of strong sorption capacity and enhanced plant performance. In contrast, unprocessed biochar addition better reduced leachate volume than granulated biochar addition, possibly resulting from the higher water retention capacity of the former. The presence of vegetation improved leachate quality and reduced leachate volume, likely due to the continuous plant nutrient uptake and water interception. We conclude that granulated biochars have a great potential in improving discharge quality from green roofs.

#### KEYWORDS

Charcoal, Green infrastructure, Post-processing, Plant performance, Stormwater management

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## 1 INTRODUCTION

Green roofs, which are rooftops with vegetation growing in engineered media, have been increasingly implemented in cities as a nature-based solution to enhance stormwater management. Roof systems generally reduce discharge volume, thereby mitigating urban flooding; however, the effects of green roofs on discharge quality have remained controversial. Substrate and vegetation are two major factors influencing discharge quality (Berndtsson, 2010). Green roofs with appropriate designs may reduce nutrient leaching and improve discharge quality by increasing substrate nutrient sorption ability and enhancing plant nutrient uptake (Berndtsson, 2010). However, the leaching of nutrients present in substrates has been recently observed (Akther et al., 2021).

Biochar, which is a porous material made from pyrolyzed biomass, has been promoted as an ideal substrate additive to green roofs due to its strong nutrient sorption ability (Laird & Rogovska, 2015) and high water retention capacity (WRC) (Razzaghi et al., 2020). However, unprocessed biochar is lightweight and susceptible to wind and water erosion (Liao et al., 2022), which may result in biochar loss and environmental pollution. Biochar granulation has been suggested as an effective means to alleviate biochar erosion loss (Liao et al., 2022). Green roofs are often exposed to high wind and intense storm events. However, little research has been done on investigating leachate quality from substrates with granulated versus unprocessed biochar additions. Biochar amendment can also influence discharge quality by affecting plant performance. Unprocessed biochars generally enhance plant growth, yet adverse impacts may occur (Buss & Mašek, 2014). A recent study shows that granular biochars enhanced plant performance on green roofs (Liao et al., 2022a), suggesting that granulated biochars may also improve discharge quality. However, few studies have examined vegetation's effect on leachate quality with the amendment of differently processed biochars.

The present study examines the effects of biochar type and vegetation on leachate quality from a green roof substrate. The leachate quality is assessed using the Canadian Council of Ministers of the Environment Water Quality Index (CCME WQI) as an integrated water quality index.

## 2 METHODS

### 2.1 Material preparation and experimental design

Two types of biochars (unprocessed vs. granulated biochars) were used in the experiment (details in Liao et al., 2022a). A commercial green roof substrate that follows the FLL guideline (*Green Roof Guidelines*, 2018) was used. Biochars were thoroughly mixed with the substrate for each growth container at a 4.5% (w/w) application rate. Two sets of containers were used for the experiment: one without vegetation and the other with one *Agastache foeniculum* seedling transplanted in each pot. The experiment was conducted in a greenhouse for 115 days. Leachate from two flushes was collected: immediately after seedling transplantation (hereinafter: first flush) and one day before the *A. foeniculum* harvest (hereinafter: final flush). For each flush, 200 mL of water was added to each pot using a watering can. A 500 mL HDPE bottle was placed beneath each container to collect the leachate.

### 2.2 Leachate volume and water quality assessments

Leachate volume was measured by the subtraction of the total mass of the bottle with leachate and the mass of the empty bottle, assuming the water density was 1 g/cm<sup>3</sup>. Leachate samples and irrigation water were assessed for pH, electrical conductivity (EC), and concentrations of total nitrogen (TN), and dissolved phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg), and sodium (Na), and total suspended solids (TSS). The CCME WQI was used to evaluate integrated leachate quality from green roofs according to drinking water quality guidelines. Seven water quality parameters (N, K, Ca, Mg, Na, pH, EC) were included to calculate the CCME WQI as follows:

$$\text{CCMEWQI} = 100 - \left( \frac{\sqrt{F_1^2 + F_2^2 + F_3^2}}{1.732} \right) \quad (1)$$

Here, F1, F2, and F3 indicate scope, frequency, and amplitude, respectively (CCME, 2017). WQI values have been grouped into five categories: poor (0–44), marginal (45–64), fair (65–79), good (80–94), and excellent (95–100).

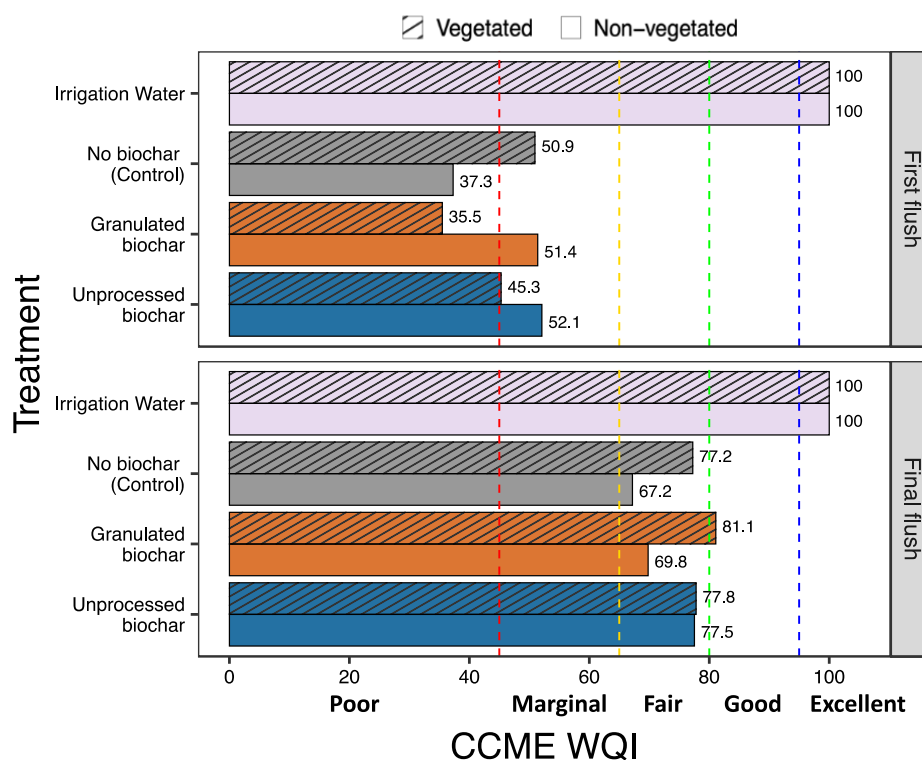
## 2.3 Statistical analysis

The effect of biochar type on leachate volume was analyzed using one-way ANOVA. Post-hoc Tukey's HSD test was performed to compare differences between two treatments. *t*-tests were conducted to assess vegetation effect (presence vs. absence) on leachate volume. Replicates for each treatment were averaged in the WQI calculations and thus no formal statistical analyses of WQI were conducted.

## 3 RESULTS AND DISCUSSION

### 3.1 Integrated leachate water quality

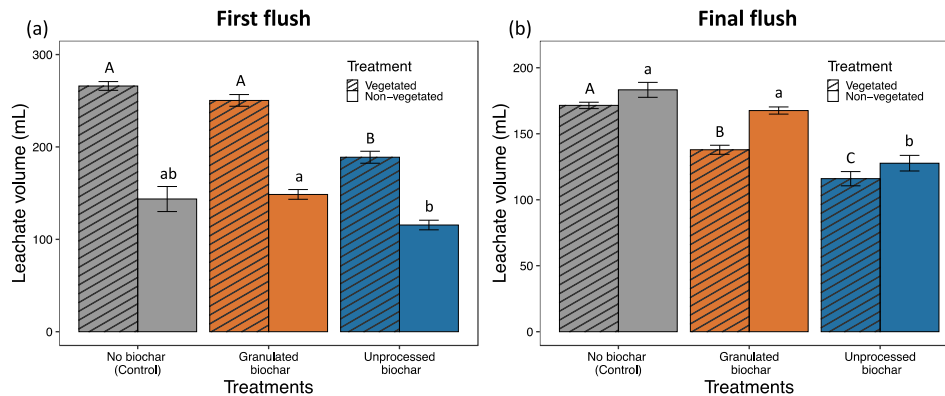
The leachate from all the treatments showed “marginal” and “poor” WQI values in the first flush (Fig. 1). In contrast, the WQI values from most treatments increased and were classified as “fair” in the final flush (Fig. 1). In the final flush, the best integrated water quality was observed for vegetated pots with granulated biochar amendment (81.1), which was classified as “good” (Fig. 1), suggesting a potential for reusing the green roof leachate water. This is likely due to the combined effects on nutrient leaching mitigation and plant performance enhancement with granulated biochars. Vegetation generally increased integrated leachate quality, resulting from enhanced plant nutrient uptake and root stabilization (Berndtsson, 2010).



**Fig. 1.** CCME WQI of leachate in the first flush (top) and final flush (bottom).

### 3.2 Leachate volume

On average, biochar amendment reduced leachate volume by 19% compared with the control (Fig. 2), suggesting a potential for reducing nutrient loading. Unprocessed biochar addition decreased leachate volume relative to the granulated biochar addition and the control (Fig. 2), likely due to the strong WRC of unprocessed biochars (Liao et al., 2022a). Vegetation reduced leachate volume by 13% in the final flush, possibly due to the enhanced water interception by plant aboveground biomass and improved substrate properties (Nagase & Dunnett, 2012).



**Fig. 2.** Leachate volume from the first flush (a) and final flush (b). Bars with different uppercase and lowercase letters differ significantly at  $p < 0.05$  according to Tukey's HSD test for vegetated and non-vegetated treatments, respectively.

## 4 CONCLUSION

Detailed analysis and discussion of this work are available in Liao et al. (2022b). Our results suggest that although unprocessed biochar amendment reduces leachate volume, the addition of granulated biochars better improves leachate water quality from green roofs than unprocessed biochar addition. This is likely due to the combined effects of strong sorption ability and enhanced plant performance with granulated biochar applications. In general, vegetation improves leachate quality and decreases leachate volume from green roofs, possibly resulting from plant nutrient uptake and root stabilization, aboveground biomass water interception, and substrate property enhancement. Our findings provide a clear incentive for field applications of granulated biochars on operational green roofs.

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