Impact of plant species on the performance of bioretention cells: establishment year of a mesocosm experiment

Impact des espèces végétales sur la performance des cellules de biorétention : suivi d'une année d'établissement en mésocosme

Henry Beral[a], Margit Kõiv-Vainik[a,b], Danielle Dagenais[c], Viviane Belle-Isle[c], Jacques Brisson[a]

[a] Institut de recherche en biologie végétale, Département de sciences biologiques, Université de Montréal, 4101, rue Sherbrooke Est, Montréal, H1X 2B2. (jacques.brisson@umontreal.ca; henry.beral@umontreal.ca)
[b] Institute of Ecology and Earth Sciences, University of Tartu, Vanemuise 46, 51003, Tartu, Estonia; (margit.koiv.vainik@ut.ee)
[c] École d'urbanisme et d'architecture de paysage, Faculté de l'aménagement, Université de Montréal, 2940, chemin de la Côte-Sainte-Catherine, Montréal, Quebec, Canada, H3C 3J7 (danielle.dagenais@umontreal.ca)

RÉSUMÉ

Les biorétentions (BRs) sont des systèmes de gestion des eaux pluviales conçus pour être intégrés en milieu urbain et capables de réduire les débits de pointe et d'augmenter la proportion d'eau infiltrée et donc traitée. Le choix des plantes de BRs est généralement fondé sur leur valeur esthétique et leur capacité à se développer dans l'habitat choisi, mais leur efficacité en matière de traitement de l'eau et leur contribution à la performance générale des BRs en climat froid sont mal connues. L'objectif de cette étude est de tester l'impact de quatre espèces présentant des caractéristiques fonctionnelles variées (*Cornus sericea*, *Iris versicolor*, *Juncus effusus, Sesleria autumnalis*), sur la performance des BRs dans le traitement du ruissellement urbain. Les résultats de la période d'acclimatation (printemps et été 2018) de l'expérience en mésocosme ont montré un taux de croissance et de production de biomasse pour *Cornus* et *Juncus* bien supérieurs à ceux de deux autres espèces. Cependant, à la fin de la saison, toutes les plantes étaient bien établies et prêtes pour la période d'expérimentation au printemps 2019. L'efficacité du traitement et les performances générales des espèces sélectionnées seront suivies et évaluées périodiquement par des analyses d'eau, de substrat, et de plante. Ces analyses complexes nous apporteront de nouvelles informations sur le rôle de la végétation dans les BRs.

ABSTRACT

Bioretention cells (BRC) are stormwater management systems designed to be integrated into urban environments and can reduce peak flows and increase the proportion of water infiltrated and therefore treated. The choice of plants for a BCR is generally based on their aesthetic value and ability to grow in the chosen habitat, but their water treatment efficiency and their contribution to the general performance of a BCR in cold climate conditions is poorly understood. The objective of this study is to test the effect of four plant species with different functional traits (*Cornus sericea*, *Iris versicolor*, *Juncus effusus, Sesleria autumnalis*) on the performance of BRCs in the treatment of urban residential runoff. The preliminary results from the acclimatisation period (spring and summer 2018) of the mesocosm experiment showed that the growth rate and biomass production of *Cornus* and *Juncus* were much better than those of the other two species. By the end of season all the plants were nicely established and ready for the experimentation period beginning in spring 2019. The treatment efficiency and general performance of the selected species will be evaluated by periodical water, plant, and substrate analyses. These complex analyses will give us new information about the role of vegetation in BRCs.

KEYWORDS

Bioretention cells, cold climate, green infrastructures, role of plants, urban stormwater

1 INTRODUCTION

For several decades, in urban areas, there has been a constant increase in stormwater runoff volumes due to an increase in impermeable surfaces. The untreated stormwater decreases the quality of receiving watercourses and puts further risk on surface and drinking water quality (Duncan, 1999). In current research, we are studying the green infrastructure developed for stormwater treatment and management, known as bioretention cells (BRCs; also called rain gardens) (Paus et al., 2015). BRCs are systems designed to be integrated into urban environments and are capable of reducing peak flows and increasing the proportion of water infiltrated, and therefore treated, in receiving watercourses (Paus et al., 2015). Vegetation provides BRCs with water volume management and treatment, in addition to ecosystem services (Dagenais et al., 2018). Therefore, the optimal choice of plant species is essential when installing BRCs (Dagenais et al., 2018; Payne et al., 2018; Read et al., 2008). The choice of plants is generally based on their aesthetic value and ability to grow in the chosen habitat. However, more scientific evidence is needed regarding plant contributions to the water treatment efficiency and to the general performance of BRCs, especially in cold climate conditions.

The objective of this study is to test the effect of four plant species with different functional traits, on the performance of BRCs in the treatment of urban residential runoff, through a mesocosm study. We are testing the effectiveness of a shrub, *Cornus sericea*, three monocotyledons, two native - *Iris versicolor*, *Juncus effusus* – and one exotic *Sesleria autumnalis*. According to previous research the graminoids with fibrous root systems play a part in nitrogen removal and shrubs with thick roots contribute to the hydraulic performance of the bioretentions (Dagenais et al., 2018; Payne et al., 2018). The current mesocosm experiment is complementary to a full-scale application study of BRCs in cold climate. The BRCs were established during spring and summer 2018 in Trois-Rivières, Quebec, Canada using the same substrate and plant species as in mesocosm experiment. Further information about the establishment year of the full-scale BRCs can be found in the extended abstract Kõiv-Vainik et al. (submitted).

2 MATERIAL AND METHODS

2.1 Experimental setup

The mesocosm-scale experiment is being conducted in the "Phytozone" greenhouse of the Institut de recherche en biologie végétale, located in the Montréal Botanical Garden (Quebec, Canada; Fig. 1). The experiment was constructed in spring 2018 to complement the monitoring of the full-scale study of the BRCs in the city of Trois-Riviéres (Kõiv-Vainik et al., submitted). Each of the 25 vertical flow BRC mesocosms (H78×L35×W35 cm) was filled with 60 cm of a commercial BRC sandy loam (6% OM) media (NATUREAUSOL®), and 3 cm of fragmented rameal wood as mulch layer. A 10 cm layer of granitic gravel (Ø 3-7 mm) with perforated pipe was used as drainage. All mesocosms have Ø 7.5 cm transparent tubes for a root camera. The 25 mesocosms were divided into 5 blocks (i.e. 5 replicates) of 5 mesocosms so that each block would contain one unplanted control (UC) and four species. The three native species – the shrub *Cornus sericea* (CS) and the native graminoids *Iris versicolor* (IV) and *Juncus effusus* (JE) – and one Mediterranean species, *Sesleria autumnalis* (SA), were randomly assigned and planted on 1st of June 2018 (Fig. 1).

Figure 1. Design and layout of mesocosm-size bioretention cell experiment.

2.2 Hydraulic loading and water composition

The average loading frequency and quantity were calculated according to the 10-year meteorological data on the precipitation amount and frequency in the Trois-Rivières area and correspond to mimicking 3 rain events per week. For a BRC area equal to 10% of the collection area, this corresponds to an input of 10 L of rainwater during the growth season and 7 L in wintertime to each mesocosm per event day (calculated from the average of 8 mm and 5 mm of precipitation, respectively). In each loading event, the inflow and outflow volumes were measured for water balance calculations. During the first growth season, rainwater collected from the roof of the greenhouse was used as an influent. As of spring 2019, the watering will be done with semi-synthetic urban runoff. Throughout the establishment period, the pH, dissolved oxygen (DO) content, salinity and electrical conductivity (EC) were measured once a month. In addition, during one loading event, the composition of one influent rainwater sample and 5 composite effluent samples (combined sample of 5 effluents of each plant species and 5 unplanted effluents) were analysed (TOC; DOC; TN, NH_4-N, NO_3-N; TP, PO_4-P; Mg, K, Ca, Fe, Cr, Mn, Ni, Cu, Zn, Cd, Pb) by an accredited laboratory.

2.3 Plant growth evaluation

Once a month, several plant parameters were measured: leaf area, plant volume, root growth, photosynthesis and stomatal conductance. At the beginning of the experiment, 3 plants per species were kept for plant tissue analyses (TN, TC, P, K, Ca, Mg, Na, Al, B, As, Cu, Fe, Mn, Zn, Cd, Co, Cr, Hg, Ni, Pb, Se; done in December 2018). These plants allowed us to obtain the initial average dry biomass weight and chemical composition of the plants. At the end of each season, the aboveground portion of the plants from each mesocosm will be cut (except for *Cornus* stems) for measurements and analyses (listed above).

3 RESULTS

3.1 Evaluation of plant growth and physiology

The native JE and CS had higher growth rates (Fig. 2) and biomass production than IV and SE. The JE aboveground biomass was 13 times greater by the end of season compared with the beginning (e.g. from 9 to 118 g DW). In comparison, the woody CS increased its leaf biomass 8 times (from 3 to 24 g DW; stem biomass is not considered because it was not cut at the end of the season), IV 3.3 times (from 2.7 to 9 g DW) and SA only 1.5 times (from 3.4 to 5.0 g DW). As expected, CS and JE also had the biggest change in leaf area (19.5 times for CS and 21.4 times for JE) when comparing measurements from May and September (median 3495 cm^2 CS > 10102 cm^2 JE > 1932 cm^2 IV > 932 cm^2 SA; Fig. 2).

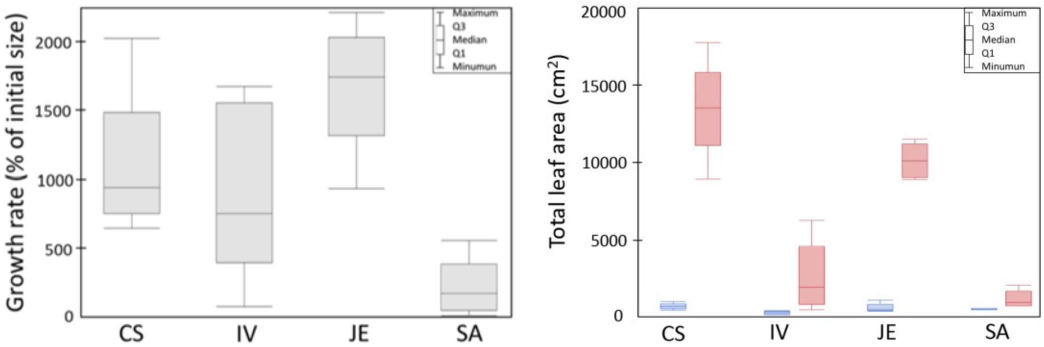

Figure 2. The growth rates (left) and leaf area (right; blue – May; red – September 2018) of *Cornus sericea* (CS), *Iris versicolor* (IV), *Juncus effusus* (JE) and *Sesleria autumnalis* (SA).

In terms of plant volume (calculated as cylindrical volume), the increase was drastic when comparing CS, IV and JE (median 18 times larger plants by September) and SA (growth only 0.9 times). When looking at the photosynthesis, the highest rate, surprisingly, was observed in SA plants, with a maximum of 24.8 μmol/m^2/s, followed by JE at 22.2 μmol/m^2/s, CS at 17.6 μmol/m^2/s and IV at 16.2 μmol/m^2/s. However, the stomatal conductance was lowest in SA (median 0.09 mmol m^2/s), as expected from the observed growth and apparent health of this species. The CS, JE and IV all had quite similar median conductance (0.33; 0.34 and 0.38 mmol m^2/s, respectively). In general, the Mediterranean SA had some establishment difficulties (e.g. one individual was replaced because of root decay) compared to the native species during the first season.

3.2 Water quality and evapotranspiration rate

The first water quality sampling shows us that there is no big difference between influent and effluent pH values (Table 1). As expected, the effluents had a much higher TOC and slightly higher nutrient content. This is probably due to the specific composition of the soil substrate (2 to 5% organic matter content) and the use of rainwater as the influent. During the establishment period, the median evapotranspiration (ET) rate in the 5 replicates was 23% with CS, 22% with JE, 16% with IV, 15% with SA and 15% in the UC. As expected, we still had relatively small plants at the end of the establishment period and this is probable why we observed no significant differences in the effluent compositions of planted and unplanted mesocosms. We can see that on average, the TOC value increases more in planted mesocosms and the TN and TP concentrations are higher in the effluent from unplanted mesocosms.

Table 1. The preliminary chemical composition of influent rainwater and effluents of the 25 mesocosms (composite samples of n=5 replicates) from one sampling event in August 2018.

Parameter	Unit	Rainwater	IV	JE	CS	SA	UC
pH	-	7.37	7.35	7.24	7.27	7.32	7.35
TOC	mg/L	0.62	31.5	21.8	22.5	30.2	20.3
TN	mg N/L	0.76	3.3	2.5	2.3	2.9	3.8
NH_4-N	mg N/L	0.09	0.08	0.06	0.07	0.06	0.08
NO_3-N	mg N/L	0.65	1.00	0.41	0.78	1.03	0.98
TP	mg P/L	0.02	0.37	0.35	0.29	0.32	0.54
PO_4-P	mg P/L	0.01	0.10	0.07	0.09	0.10	0.11

CONCLUSIONS

In general, there were no substantial differences between the main effluent compositions of the 25 mesocosms during the establishment period. Preliminary results show us that SA needs a longer time to establish in the BRCs than other species used in this study. There were visible differences between the species when looking at the general growth and the physiological indicators of plant performance, like stomatal conductance and photosynthesis rate. The acclimatisation period gave the selected plants a needed adaptation period in the new growing environment. Therefore, with more mature vegetation, the results that will be obtained during the experimentation period (starting in spring 2019) will be less affected by the variable changes that the plants go through after planting.

LIST OF REFERENCES

Dagenais, D., Brisson, J., Fletcher, T.D., 2018. The role of plants in bioretention systems; does the science underpin current guidance? Ecol. Eng. 120, 532–545. https://doi.org/10.1016/j.ecoleng.2018.07.007

Duncan, H.P., 1999. Urban stormwater quality: a statistical overview. Coop. Res. Cent. Catchment Hydrol. Report 99/3.

Kõiv-Vainik, M., Brisson, J., Beral, H., Belle-Isle, V., Langlois-Patterson, É., Abdelrahman, M., Miro, A., Dorner, S., Saint-Laurent, J., Petridis, A., Dagenais, D., submitted. Full-scale field trial for bioretention cells designed for cold climate conditions: establishment year, in: 10th International Conference on Planning and Technologies for Sustainable Management of Water in the City. Presented at the NOVATECH 2019, Lyon, France.

Paus, K.H., Muthanna, T.M., Braskerud, B.C., 2015. The hydrological performance of bioretention cells in regions with cold climates: seasonal variation and implications for design. Hydrol. Res. nh2015084. https://doi.org/10.2166/nh.2015.084

Payne, E.G.I., Pham, T., Deletic, A., Hatt, B.E., Cook, P.L.M., Fletcher, T.D., 2018. Which species? A decision-support tool to guide plant selection in stormwater biofilters. Adv. Water Resour. 113, 86–99. https://doi.org/10.1016/j.advwatres.2017.12.022

Read, J., Wevill, T., Fletcher, T., Deletic, A., 2008. Variation among plant species in pollutant removal from stormwater in biofiltration systems. Water Res. 42, 893–902. https://doi.org/10.1016/j.watres.2007.08.036