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Preparation of growth substrate to improve runoff quality from green roofs: physico-chemical characterization, sorption and plant-support experiments

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ABSTRACT
Growth substrate plays an important role in determining the quality of runoff from green roofs. However, no systematic research has been conducted to design a substrate to improve runoff quality. Hence, the present study aimed at designing and developing a green roof substrate using low-cost and environmentally-benign materials. The inorganic fraction of the substrate includes purosil, vermiculite, sand and light-weight clay aggregates (LECA); whereas the organic fraction includes coco-peat and Sargassum wightii. Through factorial design, 13 different substrate mixes were prepared and the optimum mix (20% purosil, 30% vermiculite, 10% sand, 20% LECA, 10% coco-peat and 10% S. wightii) was found to have high water holding capacity (67.6%), air filled porosity (21%), hydraulic conductivity (5524 mm/h) and low bulk density (495 kg/m³). The substrate also provided maximum support for the growth of Portulaca oleracea. Experiments with metal-contaminated influent from the down-flow of a packed reactor revealed that the green roof substrate possesses a high sorption capacity towards various metal ions.

1. Introduction

Green roofs are artificial vegetation placed on the surface of building rooftops to minimize the negative impacts of urbanization. Properly engineered green roofs have several environmental, social, aesthetic and economic benefits such as stormwater management, improved air quality, reduced heat-island effect, increased green space in urban conditions and decreased energy consumption of buildings (Getter and Rowe 2006, Vijayaraghavan 2016). Owing to this, currently, green roofs are the topic of greater interest around the world. However, it should be pointed out that research on the field of green roofs is rather limited and most of the preliminary research was conducted in European countries (Blank et al. 2013). Nevertheless, several commercial green roofs are installed in different countries with components imported from other countries. Commercial green roofs developed without proper research background and usage of imported components tended to suffer in the longer run or compromise on one or two benefits. Hence, there is a greater need to conduct in-depth research in the field of green roofs.

Engineered green roofs comprise several components (Czemiel Berndtsson 2010, Vijayaraghavan and Joshi 2014), of which substrate and vegetation are the most important. Considering that green roofs are exposed to direct sunlight and severe weather conditions on the rooftop the ideal substrate and vegetation for green roofs are required to have distinct characteristics. Plants for green roofs are expected to survive with minimum water and nutrient conditions. It is also preferable to have good ground coverage and rapid multiplying plants along with soft and short roots. These types of stringent characteristics restrict selection to only a few plant species. Notable vegetation often recommended for green roofs are types of succulents and herbaceous perennials (Dvorak and Volder 2010). On the other hand, the growth substrate of green roofs is expected to have less density, high water storage, air space and water flow. Owing to these varied characteristics it is common practice to mix several components in a varied ratio to prepare a suitable green roof substrate. Some important components used widely in green roof substrate include scoria, pumice, crushed brick and composts (Nagase and Dunnett 2011, Cao et al. 2014, Bates et al. 2015).

It is well known that plants and growth substrate are basically screened to achieve the aesthetic benefits of green roofs (Czemiel Berndtsson 2010, Vijayaraghavan and Joshi 2014). Important benefits of green roofs such as prevention of urban heat island, air pollution, water quality improvement and bio-diversity are often ignored during the selection of components for green roofs. In particular, the potential of green roofs to alter the quality of rain water is poorly understood. Rain water, while percolating through green roofs, is expected to acquire ions from substrate and vegetation. Thus, the runoff from a green roof is often polluted with dissolved and suspended impurities. Moran et al. (2003) collected water quality data from two green roofs constructed in North Carolina (USA) and the results indicated higher nutrient concentrations in the green roof runoff than those in the rainfall and control roof runoff. Berndtsson et al. (2006) indicated that some metal concentrations observed in the runoff from green roofs were equivalent to those of moderately polluted natural water. This negative impact of a green roof on rain water creates confusion in the minds of public and policy-makers. Several authors...
confirmed the potential of green roofs to act as a source for various contaminants and thereby deteriorate the runoff quality (Czemiel Berndtsson 2010, Malcolm et al. 2014, Vijayaraghavan and Raja 2015). However, no significant research effort was undertaken to improve the runoff quality. There is a potential possibility to alter the characteristics of substrates in order to improve the runoff quality. To be precise, the biosorption capacity and leaching potential of growth substrate could be altered to obtain high quality runoff.

Thus, the objective of the present research is to design a new green roof substrate using low-cost and new materials to improve runoff quality and support plant growth. Sargassum biomass was included as a substrate additive to improve the overall sorption capacity of green roof substrate. Pot experiments were conducted using Portulaca oleracea as a green roof test species for the first time.

2. Materials and methods

2.1. Vegetation

Cuttings of P. oleracea were purchased from a local nursery. The tested vegetation is known to survive prolonged drought conditions (Lara et al. 2003) and minimal nutrient conditions (Uddin et al. 2014). In addition, P. oleracea has short and soft roots, which make the species suitable for extensive green roofs.

2.2. Design of growth substrate

Four inorganic and two organic components were used to prepare the green roof substrate. Inorganic constituents include purosil (2–4 mm sieve size), vermiculite (0.5–2 mm), sand (0.25–1 mm) and light-weight expanded clay aggregate (4–10 mm). Coco-peat (0.5–1 mm) and Sargassum wightii biomass (0.5–1 mm) were used as organic fractions in the substrate to support plant growth. Purosil (processed siliceous earth) and LECA (light-weight expanded clay aggregates) were supplied by LECA India (Ahmedabad, India), whereas vermiculite (exfoliated) was procured from Srimammadurit Vermiculite Mines (Chennai, India). Brown alga, S. wightii, was collected from beaches of the Mandapam region (Tamil Nadu, India). The particular seaweed was selected in the present study as it is abundantly available in Southern parts of India and can be procured free of cost. Coco-peat samples were obtained from a nearby nursery. The composition of each component in the final substrate mix was determined on the basis of bulk density, water-holding capacity, air-filled porosity, hydraulic conductivity and plant biomass multiplication. A factorial design program was developed to optimize the composition of the green roof substrate.

Bulk density was determined as the ratio of the dry weight (oven-dried at 105 °C) to the volume of the original sample. Hydraulic conductivity was calculated through constant-head or falling-head tests depending on the particle size of the substrate (Budhu 2007). The air-filled porosity and water-holding capacity were measured for each sample according to the Australian Standard Methods for potting mixes (Standards Australia 2003).

2.3. Pot growth experiments

To evaluate the potential of different mixes to support and multiply the growth of P. oleracea, a series of pot experiments were conducted. Around 1650 mL of substrate, which corresponds to 10 cm height, was loaded into each pot. One cutting of P. oleracea was planted in each pot and artificial watering (100 mL/pot) was performed every 2 days. At the end of 40 days, the plants were completely removed from the substrate (Farrell et al. 2013) to calculate the dry weight of the plant biomass.

2.4. Down-flow packed bed reactor

In an attempt to determine the extent of leaching and pollutant binding capacity of substrate mix, a down-flow packed bed reactor was employed. Around 41.5 g of optimized substrate mix was loaded in a 2.5 cm x 35 cm (internal diameter x height) glass reactor to yield a bed height of 25 cm. During the first phase, double-deionized (DDI) water was pumped downwards at a flow rate of 0.3 L/h into the reactor to study leaching characteristics of the substrate mix. Samples, collected at the bottom of the reactor at regular time intervals, were subjected to various physico-chemical analyses such as pH, conductivity, total dissolved solids (TDS) and metal ions. In the case of analysis of metals (Al, Ca, Cd, Cr, Cu, Fe, K, Mg, Na, Ni, Pb and Zn), inductively coupled plasma-optical emission spectrometry (ICP-OES, Perkin Elmer Optima 5300 DV) was used. The experiments were continued until there was no significant variation (<5%) in conductivity values. Once leaching experiments were completed, the inlet flow was diverted to artificial metal-contaminated DDI water. During this phase, the experimental protocol was similar to that of the leaching experiments. The experiments were stopped when the concentration of one of the metal ions in the outlet reaches 0.1 times of the corresponding inlet concentration.

The artificial metal-contaminated DDI water was prepared based on the toxicity of metal ions. For the purpose of spiking, metal ions were categorized into highly toxic (Pb and Cd); toxic (Cr, Cu, Ni and Zn); mildly-toxic (Fe and Al); and non-toxic (Ca, K, Na and Mg). Thus, in the metal-contaminated DDI water, the concentrations were in the order of approximately 10, 5, 1 and 0.5 mg/L for each of non-toxic, mildly-toxic, toxic and highly-toxic metal ions, respectively.

3. Results and discussion

3.1. Characteristics of substrate and factorial design

Screening of a suitable substrate is important for the success of extensive green roofs. Green roof substrate generally comprises several inorganic and organic constituents. In practice the organic fraction should be limited to 20% in extensive green roofs (DDC 2007) to hinder the weed growth and minimize leaching. In the current investigation, inorganic ingredients used include purosil, vermiculite, sand and LECA; while organic constituents include coco-peat and S. wightii biomass. Through factorial design, 13 different green roof substrate mixes (GRSM) were formulated (Table 1) and their characteristics were studied in detail to finalize an optimum growth substrate mix.
Table 1. Factorial design of green roof components to determine optimum mix.

<table>
<thead>
<tr>
<th>Green roof substrate mix</th>
<th>Purolis (% vol)</th>
<th>Vermiculite (% vol)</th>
<th>Sand (% vol)</th>
<th>LECA (% vol)</th>
<th>Co-co-peat (% vol)</th>
<th>S. wightii (% vol)</th>
</tr>
</thead>
<tbody>
<tr>
<td>GRSM−1</td>
<td>20</td>
<td>20</td>
<td>20</td>
<td>20</td>
<td>10</td>
<td>10</td>
</tr>
<tr>
<td>GRSM−2</td>
<td>30</td>
<td>10</td>
<td>20</td>
<td>20</td>
<td>10</td>
<td>10</td>
</tr>
<tr>
<td>GRSM−3</td>
<td>10</td>
<td>30</td>
<td>20</td>
<td>20</td>
<td>10</td>
<td>10</td>
</tr>
<tr>
<td>GRSM−4</td>
<td>20</td>
<td>30</td>
<td>10</td>
<td>20</td>
<td>10</td>
<td>10</td>
</tr>
<tr>
<td>GRSM−5</td>
<td>20</td>
<td>10</td>
<td>30</td>
<td>20</td>
<td>10</td>
<td>10</td>
</tr>
<tr>
<td>GRSM−6</td>
<td>20</td>
<td>20</td>
<td>30</td>
<td>10</td>
<td>10</td>
<td>10</td>
</tr>
<tr>
<td>GRSM−7</td>
<td>20</td>
<td>20</td>
<td>10</td>
<td>30</td>
<td>10</td>
<td>10</td>
</tr>
<tr>
<td>GRSM−8</td>
<td>30</td>
<td>20</td>
<td>10</td>
<td>20</td>
<td>10</td>
<td>10</td>
</tr>
<tr>
<td>GRSM−9</td>
<td>10</td>
<td>20</td>
<td>30</td>
<td>20</td>
<td>10</td>
<td>10</td>
</tr>
<tr>
<td>GRSM−10</td>
<td>30</td>
<td>20</td>
<td>20</td>
<td>10</td>
<td>10</td>
<td>10</td>
</tr>
<tr>
<td>GRSM−11</td>
<td>10</td>
<td>20</td>
<td>20</td>
<td>30</td>
<td>10</td>
<td>10</td>
</tr>
<tr>
<td>GRSM−12</td>
<td>20</td>
<td>30</td>
<td>20</td>
<td>10</td>
<td>10</td>
<td>10</td>
</tr>
<tr>
<td>GRSM−13</td>
<td>20</td>
<td>10</td>
<td>20</td>
<td>30</td>
<td>10</td>
<td>10</td>
</tr>
</tbody>
</table>

All prepared mixes were found to have varied particle sizes in the range of 0.25–10 mm. This is due to the varied particle sizes of each substrate constituent (Table 2) and was also intentional to vary the extent of water and air to be detained by the prepared growth substrate.

Green roof substrate is expected to have low bulk density in order to reduce major load on the building roof structure. Final bulk densities were in the range of 495–763 kg/m³ (Figure 1). The presence of LECA (238 kg/m³) and vermiculite (279 kg/m³) decreased the bulk density of the growth substrate. On the other hand, the sand (1611 kg/m³) increased the bulk density of the final mix. It is important to note that the bulk density of prepared green roof substrate (495 kg/m³) was less than other commercial substrates reported in the literature, such as 840 kg/m³ for S. wightii (Farrell et al. 2013).

Water holding capacity is an important factor that allows a green roof to survive in drought conditions. It also plays a crucial part in delaying peak flow during storm events thereby avoiding flash floods. Growth substrates are expected to possess WHC greater than 20% in extensive green roofs (FLL 2002). Substrate components such as S. wightii (WHC = 260%), coco-peat (WHC = 46.3%) and vermiculite (WHC = 62.5%) played a crucial role in improving the WHC of a prepared mix (Table 2). Owing to these components, the WHC of substrate mixes were in the range of 60–68.5% (Figure 1).

Plants need good air space for proper growth. Compacted soil decreases oxygen and hence limits plant growth. Air filled porosity (AFP) is the factor used to govern the air space between the pores and the value should be greater than 10% in extensive roofs (FLL 2002). Substrate ingredients which are a relatively larger size, such as LECA (AFP = 31.4%) and vermiculite (AFP = 31.1%), improved the AFP of the final mix. For the different mixes generated, the AFP values were in the range of 16.7–21.0% (Figure 1).

Flow through a green roof is expected to be smooth and steady. Ponding at the surface of a green roof should be avoided to prevent roof leakage, soil erosion and excess weight. In other words, hydraulic conductivity (HC) should be high, to be precise greater than 3600 mm/h (FLL 2002). Similar to AFP results, bigger sized particles, such as LECA, provided larger pore spaces and thereby enhanced HC. Organic constituents usually decrease HC. As the time progresses, organic fractions tend to dissociate, blocking the pores and decreasing HC. For instance, S. wightii exhibited HC of 340 mm/h. Hence, it is desirable to have a low organic fraction to have uniform flow. HC were in the order of 3860–7530 mm/h for the examined mixes (Figure 1).

The most important requisite for any green roof substrate is its potential to support vegetation. Growth substrates of extensive green roofs are generally expected to support only a few vegetation species owing to the presence of minimal organic fraction, thin substrate layer, irregular irrigation and extreme weather conditions on the rooftop (Nagase and Dunnett 2011). Interestingly, P. oleracea survived and multiplied exceedingly well in all different mixes examined. Of the different substrate constituents used, maximum biomass multiplication was provided by sole-coco-peat medium with multiplication up to 796%. It is also very interesting to understand that P. oleracea survived even in sand and LECA as substrate mediums with biomass multiplication of 119% and 130%, respectively. On the other hand, Sargassum biomass as a sole substrate medium provided no significant improvement in the multiplication of biomass and also visually impacted the plant with changes in colour and a weakening of shoots. This may be due to the presence of excess Na, K, Ca and Mg ions in Sargassum biomass which affected the growth the P. oleracea. Teixeira and Carvalho (2009) studied the influence of saline stress on P. oleracea and identified that high salinity levels had a detrimental effect on P. oleracea. However, the mix of all these components provided interesting results. Some of the mixes provided biomass multiplication up to 2.72 times within 40 days (Figure 1). Visual observation revealed no significant colour changes and flower blooming in any of the mixes in comparison with P. oleracea planted in sole coco-peat substrate pot.

Of all the substrate mixes examined, it was identified that GRSM-4 (20% purolis, 30% vermiculite, 10% sand, 20% LECA, 10% coco-peat and 10% S. wightii) was identified as optimal growth medium to provide relatively low BD, high WHC, AFP and HC and plant biomass multiplication of the mixes examined.

Table 2. Characteristics of different substrate components and optimum green roof substrate mix (GRSM-4).

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Particle size (mm)</th>
<th>Bulk density (kg/m³)</th>
<th>Water holding capacity (%)</th>
<th>Air filled porosity (%)</th>
<th>Hydraulic conductivity (mm/h)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Purolis</td>
<td>2–4</td>
<td>695</td>
<td>55.0</td>
<td>10.1</td>
<td>1145</td>
</tr>
<tr>
<td>Vermiculite</td>
<td>0.5–2</td>
<td>279</td>
<td>62.5</td>
<td>31.1</td>
<td>2170</td>
</tr>
<tr>
<td>Sand</td>
<td>0.25–1</td>
<td>1611</td>
<td>30.5</td>
<td>10.3</td>
<td>3850</td>
</tr>
<tr>
<td>LECA</td>
<td>4–10</td>
<td>238</td>
<td>20.0</td>
<td>31.4</td>
<td>19,500</td>
</tr>
<tr>
<td>Coco-peat</td>
<td>0.5–1</td>
<td>161</td>
<td>46.3</td>
<td>10.7</td>
<td>3280</td>
</tr>
<tr>
<td>S. wightii</td>
<td>0.5–1</td>
<td>498</td>
<td>260</td>
<td>12.2</td>
<td>340</td>
</tr>
<tr>
<td>Green roof substrate mix</td>
<td>0.25–10</td>
<td>495</td>
<td>67.6</td>
<td>21.0</td>
<td>5524</td>
</tr>
</tbody>
</table>
3.2. Continuous-flow sorption experiments

The optimized green roof substrate was further examined for its leaching potential and sorption capacity in a down-flow packed bed reactor. One of the major hindrances of green roof is the quality of runoff (Czemiel Berndtsson 2010). The potential of green roof to turn clean rain water into muddy brownish water is not acceptable. In order to evaluate the leaching tendency of prepared green roof substrate, initial experiments were conducted in down-flow packed bed reactor loaded with unwashed substrate with DDI water as influent. The concentrations of several ions in the effluent were very high during initial periods of reactor operation. However, a significant decrease was observed as the time progresses. Light metals such as Na, Ca, K and Mg were predominantly leached from the substrate mix (Figure 2). For instance, within 10 min of reactor operation, Ca, K, Mg and Na concentrations in the effluent were in the order of 6.2, 162, 19.0 and 183 mg/L, respectively. Considering that substrate constituents such as vermiculite, purosil, Sargassum biomass and coco-peat were rich with light metals, the leachates were found to comprise these metals. It should also be noted that these metal ions are macro-nutrients for plant growth and abundantly available in soil constituents. The reactor effluent was also found to contain a significant amount of Al, Fe, Cu and Zn ions. Vermiculite is rich in Al and Fe (Malandrino et al. 2006); whereas other heavy metal ions are commonly present in clay-minerals. No evidence was found to confirm the presence of Cr, Pb, Cd and Ni in the effluent during the entire reactor operation.

The effluent pH was always near neutral or slightly alkaline (Figure 2). This is due to leaching of alkaline constituents from the substrate. The potential of green roof substrate to alkalinize the runoff is an important benefit especially for regions which receive acid rain. As far as conductivity was concerned, the values were very high in the beginning and subsided progressively (Figure 2). At the end of 1200 min of reactor operation the conductivity value
of the effluent decreased by 84.5%. A similar trend was observed with TDS values.

Further attempts were made to understand the binding capacity of green roof substrate towards different pollutants. For this purpose, artificial metal-contaminated DDI water was replaced as the reactor influent. Figure 3 represents breakthrough curves obtained as a result of contact between green roof substrate loaded in reactor and artificial metal-contaminated DDI water. The reactor was operated for 1200 min with a bed volume of 48.9. Up to 1080 min, no Pb and Cd ions were detected in the effluent. This showed a high removal efficiency of about 99.9% for Pb and Cd. Green roof substrate also showed good affinity towards Cr and Cu as their C/C₀ (output concentration/inlet concentration) values were less than 0.04 at the end of 20 h of reactor operation (Table 3). Up to 120 min, the reactor effluent was free of Zn. Further

Table 3. Performance of green roof substrate-loaded packed bed reactor during treatment of metal-contaminated DDI water.

<table>
<thead>
<tr>
<th>Metal</th>
<th>Uptake (mg/g)</th>
<th>Removal efficiency (%)</th>
<th>(C/C₀) at 1200 min</th>
</tr>
</thead>
<tbody>
<tr>
<td>Al</td>
<td>0.49</td>
<td>95.7</td>
<td>0.07</td>
</tr>
<tr>
<td>Cd</td>
<td>0.05</td>
<td>99.9</td>
<td>0.01</td>
</tr>
<tr>
<td>Cr</td>
<td>0.10</td>
<td>97.9</td>
<td>0.04</td>
</tr>
<tr>
<td>Cu</td>
<td>0.10</td>
<td>98.5</td>
<td>0.04</td>
</tr>
<tr>
<td>Fe</td>
<td>0.49</td>
<td>94.6</td>
<td>0.10</td>
</tr>
<tr>
<td>Ni</td>
<td>0.10</td>
<td>93.7</td>
<td>0.09</td>
</tr>
<tr>
<td>Pb</td>
<td>0.05</td>
<td>99.9</td>
<td>0.10</td>
</tr>
<tr>
<td>Zn</td>
<td>0.10</td>
<td>99.1</td>
<td>0.02</td>
</tr>
</tbody>
</table>

Figure 2. Characteristics of leachates from green roof substrate loaded packed bed reactor (bed height = 25 cm; flow rate = 0.3 L/h).

Figure 3. Breakthrough curves for different metal ions obtained during continuous flow-through experiments in green roof substrate loaded packed bed reactor using metal-contaminated DDI water as influent (bed height = 25 cm; flow rate = 0.3 L/h).

Figure 4. Characteristics of effluent obtained during continuous flow-through experiments in green roof substrate loaded packed bed reactor using metal-contaminated DDI water as influent (bed height = 25 cm; flow rate = 0.3 L/h).
increase in reactor operation gradually increased Zn concentration in the effluent and finally reached C/C0 value of 0.02 at the end of 20 h. The green roof substrate loaded reactor even showed good removal efficiency towards Al and Fe (Figure 3) in the order of 95.7% and 94.6% for Al and Fe, respectively. The high sorption performance of the green roof substrate was possibly due to the presence of Sargassum biomass. It is well known that Sargassum biomass is an efficient biosorbent for all heavy metal ions (Davis et al. 2003, Vijayaraghavan and Yun 2008). The reactor was eventually stopped at 1200 min since the C/C0 of Ni exceeded the breakthrough limit (C/C0 = 0.1). Through these results, we understood that the green roof substrate exhibited varied binding capacities to different metal ions as evident through % removal efficiency and metal uptake values (Table 3). In general, the preference of a remediator towards a metal ion in a multi-solute system depends on several factors including the nature of functional groups, concentration and speciation of the metal ion as well as competition from other metals (Vijayaraghavan and Yun 2008). However, in the present study, the green roof substrate (remediator) was a mixture of several constituents of different origin and the solute was a mixture of several metal ions at different concentrations. Hence, predicting the exact mechanism of metal removal may be complex. Nevertheless, the presence of Sargassum biomass, coco-peat and vermiculite improved the sorption capacity of the growth substrate (Álvarez-Ayuso and García-Sánchez 2003, Romera et al. 2006, Vijayaraghavan et al. 2016). Also, the release of light metal ions from the growth substrate (Figure 4) during the entire reactor operation may provide some insights into the removal mechanism. The gradual leaching of these light metal ions can be correlated with sorption of heavy metal ions with ion-exchange as a major removal mechanism of green roof substrate. The reactor also showed potential to decrease the acidity of the influent water (Figure 4) as well as increase the conductivity (Figure 4) and TDS values. However, both conductivity and TDS of effluent steadily decreased with the progression of the reactor operation.

4. Conclusions

Runoff quality is critical for the success of green roofs and the growth substrate plays an important role in determining the quality of water from green roofs. To be precise, the sorption capacity and less leaching tendency should be considered as important factors during selection of substrate components for improved runoff quality from green roofs. This research designed and developed a new green roof substrate based on several physico-chemical and biological parameters. Based on factorial design, optimum substrate mix (20% purosil, 30% vermiculite, 10% sand, 20% LECA, 10% coco-peat and 10% S. wightii) was prepared which exhibited high WHC (67.6%), AFP (21%), hydraulnic conductivity (5524 mm/h) and low bulk density (495 kg/m3). Due to the presence of coco-peat, the growth medium multiplied the biomass of P. oleracea by 2.72 times within 40 days. During experiments from a down-flow packed reactor, the developed green roof substrate showed potential to leach different constituents; however their concentrations subsided as the bed volume increased. Green roof substrate also showed a high potential to bind heavy metal ions such as Al, Cd, Cr, Cu, Fe, Ni, Pb and Zn with removal efficiencies greater than 93.7% for a bed volume of 48.9. Based on the results, the developed growth substrate offers multiple economic and environmental benefits, especially based on runoff quality. Future experimental research should focus on performance of the substrate in real green roofs after rain events and the potential of the substrate to support different plant species.

Disclosure statement

No potential conflict of interest was reported by the authors.

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