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Research Paper

Application of seaweed as substrate additive in green roofs: Enhancement of water retention and sorption capacity

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HIGHLIGHTS

- New green roof substrate was developed with *Turbinaria conoides* as additive.
- Substrate provided high moisture retention, air space and draining properties.
- Green roofs showed potential to delay runoff.
- Green roofs acted as sink for various heavy metal ions with high sorption capacity.

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ABSTRACT

Green roof substrates are usually designed to achieve desirable characteristics such as low bulk density, preparation cost, high water holding capacity (WHC), hydraulic conductivity (HC) and airfilled porosity (AFP). However, no importance is given to sorption capacity or leaching potential of substrate. Thus, in the present study, novel attempt was made to incorporate a brown-seaweed (*Turbinaria conoides*) in growth substrate to enhance the runoff quality from green roofs. The green roof substrate, prepared using 30% perlite, 20% vermiculite, 10% sand, 20% crushed brick, 10% cocopeat and 10% *T. conoides*, was found to have favourable characteristics such as low bulk density (477.7 kg/m^3), high WHC (49.5%), AFP (20.5%) and HC (4210 mm/h). With the aid of down-flow fixed column, sorption capacity of green roof substrate towards various metal ions (Na, K, Ca, Mg, Al, Fe, Cd, Cu, Cr, Ni, Pb and Zn) was examined and results indicated that the column was able to operate for 1440 min at a flow rate of 5 mL/min before outlet Ni concentration reached the inlet. Green roof experiments were performed using pilot-scale assemblies with *Portulaca grandiflora* as vegetation. Under rainfall simulations, it was observed that vegetated-green roof assemblies acted as a sink for various metal ions and produced better runoff. In addition, green roofs buffered acidic rain and delayed runoff generation.

1. Introduction

With the rapid urbanization, tall buildings and other new developments are made at the expense of green areas in cities. This resulted in shortage of greenery which in turn causes a decrease in canopy interception and transpiration within the city leading to increased temperature and decreased air humidity (Berndtsson, 2010). In addition, buildings are also responsible for 33% of greenhouse gas emission globally through high rate of energy and resource consumption (Berardi, Ghaffarianhoseini, & Ghaffarianhoseini, 2014). These problems may be partially solved by altering buildings' rooftop properties. In recent years, green roofs (also called as vegetated roofs, living roofs or eco-roofs) are identified as a practical and valuable strategy to make sustainable buildings in urban areas.

Green roofs are basically roofs planted with vegetation on the top of growth medium (substrate). Depending on the location and space availability, green roofs generally comprise of vegetation at the top, followed by substrate, filter fabric, drainage element, root barrier, insulation and waterproofing layer. Green roofs present numerous economic and social benefits in addition to more obvious environmental advantages such as: improved insulation of the building; stormwater attenuation; noise insulation; reduced heat-island effect; extended roof life; habitat for pollinators; aesthetic value and enhanced marketability of property; improved air quality

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(Bates, Sadler, Greswell, & MacKay, 2015; Berardi et al., 2014; Chen, 2013). As a result of these positive effects, green roofs are becoming popular in many countries (Chen, 2013; Vijayaraghavan & Raja, 2014a). Several large-scale green roofs were established in European, American and few Asian countries. However, recent research reports pointed out that most of the commercial green roofs are not optimized to achieve the environmental/economic benefits associated with greening the rooftops (Berndtsson, 2010). To be precise, the focus of commercial green roof developers is usually related with development of substrate mix and management (watering and fertilization) to support vegetation. The performance of green roofs towards achieving various benefits is not well known. One such important benefit of green roof is enhancement of stormwater runoff quality. However, recent research reports proved that green roofs can also potentially degrade the quality of rain water with pollutants released from soil, plants and fertilizers (Berndtsson, Emilsson, & Bengtsson, 2006; Moran, Hunt, & Jennings, 2003; Vijayaraghavan & Joshi, 2014). Rainwater is generally considered as non-polluted but may be acidic, and contains substantial amounts of nitrates and traces of other pollutants such as heavy metals and pesticides depending on the local pollution sources and prevailing winds (Berndtsson, 2010). Upon percolation through green roof system, ions from substrate components will be leached into the influent and the runoff will have a higher concentration of the ion than the rain water (Gnecco, Palla, Lanza, & La Barbera, 2013). This is further complicated by plant uptake and fertilization practices which remove or add nutrients, respectively. However, till now, only runoff quality assessment studies were performed (Teemusk & Mander, 2007; Vijayaraghavan & Joshi, 2014) and no in-depth investigation has been made to improve the quality of runoffs generated by green roofs.

The improvement in the runoff quality from green roofs can be achieved through proper selection of substrate components and plants. Green roof substrates should be light weight, cheap, and possess high water retention capacity, hydraulic conductivity and air-filled porosity. However, no importance was given to sorption capacity or leaching potential of substrate. Considering the green roof substrate mainly comprise of inorganic constituents, it is advisable to mix an efficient sorbent which improve the sorption capacity of green roof substrate. Therefore, through this study, a brown-seaweed (*Turbinaria conoides*) was supplemented with the green roof substrate to enhance the sorption capacity as well as support plant growth. *T. conoides* is a well-known sorbent for various heavy metal ions (Vijayaraghavan, Joshi, & Kamala-Kannan, 2012) and it comprise of high NPK ratio (Sunarpi, Jupri, Kurnianingsih, Julisaniah, & Nikmatullah, 2010). Therefore, the objective of the present study was to develop a novel seaweed-based growth substrate for green roofs. Packed column assembly was used to evaluate sorption capacity of substrate, whereas pilot-scale green roof assemblies were employed to examine the runoff quality and plant support.

2. Materials and methods

2.1. Substrate components and mixture preparation

Based on the procedures developed by Vijayaraghavan and Raja (2014a), green roof substrate was developed using expanded perlite, exfoliated vermiculite, sand, crushed brick and coco-peat. The substrate exhibited favourable physico-chemical properties as well as supported maximum plant growth. However, the sorption capacity was found to be limited. Thus, in the present study, the organic content (coco-peat) was replaced with equal volume mix of *T. conoides* and coco-peat. The modified green roof growth substrate comprises of (on volume basis) 30% perlite, 20% vermiculite, 10% sand, 20% crushed brick, 10% coco-peat and 10% *T. conoides*.

Expanded perlite (0.25–1 mm) was purchased from Keltech Energies Ltd. (Bangalore, India), whereas exfoliated vermiculite (0.5–2 mm) was procured from Sriramamaruti Vermiculite Mines (Chennai, India). Other inorganic constituents (sand (0.25–1 mm) and crushed brick (4–10 mm)) were obtained from commercial shops. Samples of *T. conoides* were collected from the Mandapam region of Tamil Nadu, India. Coco-peat samples were collected from a local nursery. Both organic constituents were initially dried under sunlight for three days and further dried in the oven at 60 °C for 24 h. The samples were then grounded and subsequently sieved to obtain average particle sizes in the range of 0.5–1 mm. The physical and chemical characteristics of green roof substrate were discussed in Section 3.1. The bulk density was calculated as the ratio of the dry mass (dried at 105 °C) to the volume of the undisturbed sample. Bulk density (at maximum water holding capacity) was measured as per FLL guidelines (FLL, 2002). Hydraulic conductivity was determined through constant-head or falling-head tests depending on the substrate size (Budhu, 2007). The water holding capacity (WHC) and air filled porosity (AFP) were determined according to the Australian Standard Methods for potting mixes (Standards Australia, 2003).

2.2. Preparation of metal-spiked water

Metal-spiked water was prepared by artificial addition of metal ions by mixing their respective nitrate salts in either deionized (DI) or rain water. Analytical grades of $NaNO_3$, KNO_3, $Ca(NO_3)_2{\cdot}4H_2O$, $Mg(NO_3)_2{\cdot}6H_2O$, $Al(NO_3)_3{\cdot}9H_2O$, $Fe(NO_3)_3{\cdot}9H_2O$, $Cr(NO_3)_3{\cdot}9H_2O$, $Zn(NO_3)_2{\cdot}6H_2O$, $Cu(NO_3)_2{\cdot}3H_2O$, $Ni(NO_3)_2{\cdot}6H_2O$, $Pb(NO_3)_2$ and $Cd(NO_3)_2{\cdot}4H_2O$ were purchased from Sigma–Aldrich, India. To decide upon the concentration to be spiked, metal ions were classified into four groups: non-toxic (Na, K, Ca and Mg), mild-toxic (Al and Fe), toxic (Ni, Zn, Cu and Cr) and highly toxic (Pb and Cd) metals. In the spiked-rain or DI water, the concentrations were in the order of approximately 0.5, 1, 5 and 10 mg/L for each of highly toxic, toxic, mild-toxic and non-toxic metal ions, respectively (Vijayaraghavan & Raja, 2014a).

2.3. Sorption experiments

Continuous-flow experiments were conducted in a down-flow packed column (height = 35 cm; internal diameter = 2.5 cm). Around 55.9 g of green roof substrate was loaded within the column to obtain a bed height of 25 cm. In order to distribute the influent uniformly, a 3 cm layer of glass beads was placed at the top of the column. The influent (metal-spiked DI water) at pH 5.5 was pumped downwards through the column at a flow rate of 0.3 L/h using a peristaltic pump. Samples were collected at the column exit at regular time intervals and analyzed immediately for metal concentrations using inductively coupled plasma-optical emission spectrometry (ICP-OES, Perkin Elmer Optima 5300 DV).

Column uptake and % removal were calculated according to Vijayaraghavan and Yun (2008). The total quantity of metal mass adsorbed in the column is calculated from the area above the breakthrough curve (outlet metal concentration vs. time) multiplied by the flow rate. Dividing the metal mass by the substrate mass (M) leads to the uptake capacity (Q) of the substrate. On the other hand, metal removal efficiency (%) with respect to flow volume can be calculated from the ratio of metal mass adsorbed to the total amount of metal ions sent to the column.

2.4. Study site and green roof components

Green roof experiments were carried out on the rooftop of Mechanical Sciences Block (IIT Madras, India). Pilot-scale green roof assemblies (50 cm × 50 cm × 25 cm glass) were designed and were