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Pilot-scale evaluation of green roofs with *Sargassum* biomass as an additive to improve runoff quality

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ABSTRACT

Green roofs have the potential to be used as a pollutant-sink in urban environments. Unfortunately, until now no systematic study has been conducted to enhance the runoff quality from green roofs. The present work investigates the viability of using low-cost aggregates along with a biosorbent (*Sargassum* biomass) to prepare substrate mix for extensive green roofs to improve runoff quality. We have used (on a volume basis) 30% perlite, 20% vermiculite, 10% sand, 20% crushed brick, 10% coco-peat and 10% *Sargassum* biomass to prepare green roof substrate. The developed green roof substrate was found to have low bulk density (487 kg/m^3), high water retention capacity (58.5%), air filled porosity (19.5%), and hydraulic conductivity (4195 mm/h). Through laboratory packed column study, we identified superior sorption capacity of green roof substrate towards various metal ions such as Al, Fe, Cr, Cu, Ni, Zn, Cd and Pb. Roof-top experiments in pilot-scale green roof assemblies with *Portulaca grandiflora* as vegetation were conducted for several artificial rain events (unspiked and metal-spiked). Results based on unspiked artificial rain events suggested that concentrations of most of the chemical components in runoff were highest during the beginning of rain events and thereafter subsided during the subsequent rain events. Metal-spiked artificial rain events revealed that green roofs acted as a sink for various metal ions and generated better runoff, whose quality was significantly less than fresh water standards. Green roofs also showed the potential to neutralize the acidic nature of inlet water and delay runoff generation. Significant differences were also observed between non-vegetated and vegetated green roof assemblies in runoff quality and quantity, with the latter producing better results.

1. Introduction

Green (vegetated or living) roofs are growing in popularity around the world owing to their unique environmental and social benefits. Green roofs integrate vegetation with underutilized urban buildings thereby lessening several negative effects of buildings on local ecosystems. They can reduce buildings' energy consumption and mitigate storm-water runoff thereby reducing flash flood. The addition of vegetation and soil to urban buildings are known to increase sound insulation, and improve fire resistance and the longevity of roof membrane (Oberndorfer et al., 2007; Rowe, 2011). Other potential benefits include air quality improvement, reduction of urban heat-island effect, improvement in the efficiency of solar panels and providing urban environments with more green space (Chemisana and Lamnatou, 2014).

Green roofs are usually comprised of following layers: vegetation, substrate, filter, drainage, root barrier and waterproofing layer (Fig. 1a). The type of each of these layers depends on the type of green roof itself (extensive or intensive). In general, extensive green roofs (thin substrate layer, light weight, drought tolerant plants and low maintenance) are more common than intensive green roofs (thick substrate layer, larger weight, wide variety of garden plants and high maintenance). For extensive green roofs, drought tolerant plants such as sedum are generally preferred; however in some cases grasses, herbaceous perennials and annuals are used (Rowe, 2011). In the case of substrate, wide variety of light-weight inorganic materials such as crushed concrete, expanded slate, expanded clay, crushed brick, volcanic pumice, scoria and sand are used (Nagase and Dunnett, 2011). Usually, green roof substrate is prepared by mixing several inorganic materials to achieve desirable characteristics along with minimal organic matter, such as green waste compost and mulch. As a filter layer, polypropylene or polyester geotextile membranes are usually employed (Pérez et al., 2012). These retain the substrate component, but allow water to pass through the drainage element.

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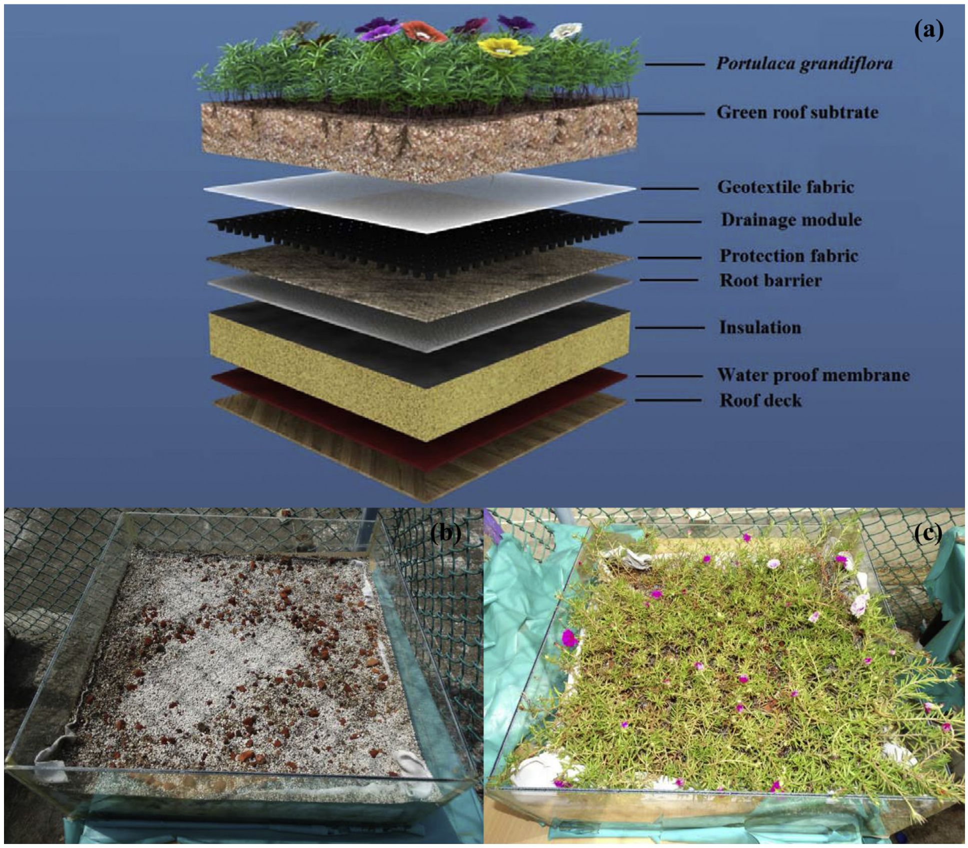

Fig. 1. Schematic diagram of green roof (a) and green roof assemblies (b) GA-1; (c) GA-2 used in the present study. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

There are two types of drainage systems usually employed in commercial green roof systems viz. plastic drainage modules and light-weight drainage granules (light-weight expanded clay aggregates). Drainage modules are widely used in medium and large scale green roofs, whereas light-weight granules are suitable for small scale systems due to their simplicity, however, in some cases it may be all that is necessary to lift the main substrate above the draining water.

Recent green roof research has focused on plant selection to promote biodiversity (Cook-Patton and Bauerle, 2012), thermal benefits including reduction in urban heat island effect (Kolokotsa et al., 2013), and hydrological properties, in particular, attenuation and retention of stormwater by green roofs (Berndtsson, 2010). Furthermore, the role of green roofs in air purification (Yang et al., 2008), sound insulation (Renterghem and Botteldooren, 2011), aesthetics (Jungels et al., 2013) and roof protection (Rowe, 2011) has been explored. An important factor which is often overlooked in previous studies published in the literature is the runoff quality from green roofs (Berndtsson et al., 2006, 2009). Although without adequate evidence, it is often assumed that green roofs improve the runoff water quality compared to hard roofs (Berndtsson et al., 2009). However, green roofs can also potentially contribute to the degradation of the quality of receiving waters with pollutants released from soil, plants and fertilizers (Vijayaraghavan et al., 2012). Of the very limited literature on runoff quality assessment, green roofs are generally regarded as a source of contaminants (Moran et al., 2003; Berndtsson et al., 2006; Berndtsson, 2010; Vijayaraghavan et al., 2012). The presence of vegetation and growth substrate potentially contributes to pollutants released into water. However, not much effort has been made to improve the quality of runoffs generated by green roofs.

Seaweeds have recently been identified as excellent sorbents for various organic and inorganic contaminants (Romera et al., 2006; Vijayaraghavan and Yun, 2008). In particular, the brown seaweed *Sargassum* species have shown potential to continuously sorb and immobilize various pollutants (Vijayaraghavan et al., 2009). Furthermore, seaweeds are rich in minerals and nutrients that are important for plant growth. Hence, seaweeds as an additive in green roof substrate have the potential to improve the quality of runoffs and support plant growth. Therefore, the objective of this paper is to explore the possibility of seaweed-based sorbent in growth substrate to improve the quality of green roof runoff. To our knowledge, till date, no study has been conducted on the possibility of an additive to enhance the sorption capacity of green roof substrate. Rainfall simulations on various pilot-scale green roof assemblies were used to evaluate the runoff quality based on various physico-chemical parameters.

2. Materials and methods

2.1. Study site and design of green roofs

The rooftop of Mechanical Sciences Block (IIT Madras, India) was used to conduct green roof experiments from June to September 2013. Several green roof assemblies were custom-designed (50 cm × 50 cm × 25 cm glass assemblies) (Fig. 1b and c), with the same principle as full-scale vegetated roofs. All assemblies were placed on a 4^0 slope to replicate general roof design. The runoff was collected in a measuring beaker through the opening at the bottom of the assembly. Generally, each assembly consist of three components, an uppermost layer (10 cm thick growing substrate to support plant growth), an intermediate layer