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Using recycled aggregates in green roof substrates for plant diversity

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ABSTRACT

Extensive green roofs are becoming a popular tool for restoring green infrastructure in urban areas, particularly biodiverse habitats such as post-industrial/brownfield sites. This study investigated the use of six recycled lightweight aggregates and combinations of them in green roof growing substrate, to determine their effectiveness for enhancing plant abundance and species diversity. In two separate experiments, we examined the roles of substrate type and depth on the establishment of a perennial wildflower mix over a 15-month period. We found that some of the alternative substrates are comparable to the widely used crushed red brick aggregate (predominantly found in commercial green roof growing substrate) for supporting plant establishment. For some materials such as clay pellets, there was increased plant coverage and a higher number of plant species than in any other substrate. Substrates that were produced from a blend of two or three aggregate types also supported higher plant abundance and diversity. Generally, increasing substrate depth improved plant establishment, however this effect was not consistent across substrates. We conclude that recycled materials may be viable constituents of growing substrate for green roofs and they may improve green roof resilience, through increased plant cover and diversity. The results could provide evidence to support the construction of mosaic habitat types on single roofs using various substrate blends.

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1. Introduction

Green roofs—rooftops that have been purposefully vegetated (Oberndorfer et al., 2007) either with low growing *Sedum* plants, wildflowers, grasses or shrubs and trees, are an emerging green technology that is becoming increasingly popular in urban environments due to the many benefits they provide. One such benefit is their potential to restore biodiversity in urban landscapes (Gedge, 2001; Grant et al., 2003; Sadler et al., 2011; Ishimatsu and Ito, 2013; Madre et al., 2014). There is an increasing body of evidence demonstrating that green roofs are able to support high biodiversity if designed appropriately (Brenneisen, 2006; Kadas, 2007; Baumann and Kasten, 2010; Tonietto et al., 2011) and increasing recognition that rich biodiversity in cities can have enormous potential to mitigate the effects of climate change through the enhancement of urban resilience and sustainability (Niemelä, 2014).

Extensive green roofs are generally designed with a substrate layer (up to 150 mm deep) that contains a high (up to 90%) percentage of aggregate and a small amount of organic material. This not only provides a low nutrient growing substrate ideal for green roof vegetation (Molineux et al., 2009; Molineux, 2010; Nagase and Dunnett, 2011) but also reduces extra roof weight. Problems can occur with either the addition of ‘soil’ and its attending clay fraction causing reduced water transmissivity or excessive compost/organic matter risking substrate shrinkage (Snodgrass and Snodgrass, 2006). Extensive green roofs are often vegetated using blankets, comprised of up to 12 different *Sedum* species and are rolled out over the substrate layer to provide an instant ‘green’ effect (Emilsson and Rolf, 2004). Other types of planting that are popular include wildflower and grass blankets, plug-planted systems (with either *Sedum* or wildflower species) and seeded systems. Biodiversity roofs tend to use both plug-plants and seeds and often support local species that naturally invade the roof (Bates et al., 2013) such as *Buddleia*,*Chenopodium* spp., *Trifolium* spp., tree species seedlings (*Salix* spp.) and various grass species. These types of roofs are generally designed to mimic natural wasteland areas where bare ground can be colonized by wildflowers and grasses, with succession proceeding to scrub and finally woodland, allowing a wide range of wildlife to become established (Gibson, 1998; Angold et al., 2006). These roof level habitats often naturally retard succession due to limitations of substrate depth, water holding capacity and nutrient availability

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(Olly et al., 2011; Sadler et al., 2011). However, such stresses might also maintain a higher biodiversity level if managed effectively (Benvenuti, 2014), as dominating species can be removed (Bates et al., 2013).

The aggregate content provides the growing substrate with physical characteristics such as optimal water retention and free-draining abilities as well as good aeration, to prevent anaerobic conditions associated with compacted soils (Snodgrass and Snodgrass, 2006). Water holding capacity is of particular importance for vegetation especially during the dry summer months, and is affected by not only the substrate depth (VanWoert et al., 2005; Olly et al., 2011), but also by its type/composition (Graceson et al., 2013). Although many studies have looked at the effect of commercially available substrates on green roof hydrolytic properties (Bengtsson, 2005; Morgan et al., 2013; Wang et al., 2013; Zheng et al., 2013; Berretta et al., 2014; Volder and Dvorak, 2014), there has been little research on alternative recycled materials for use in green roof growing substrate (Molineux et al., 2009; Mickovski et al., 2013). Furthermore, fewer studies still have focused on their suitability for plant performance and diversity (MacIvor et al., 2013) and the role of different aggregates in affecting the process of succession is unknown. Successional processes on green roofs are likely to be extremely slow, mainly driven by the lack of water and nutrients (Emilsson, 2008; Bates et al., 2013) and previous experiments have concentrated upon annual plants (Nagase and Dunnett, 2013). Our aim was to determine whether different aggregates can provide satisfactory growing conditions for perennial plant species. During secondary succession, perennial herbs and grasses provide the greatest array of niches and support highest numbers of associated insects (Edwards-Jones and Brown, 1993) and maximise the biodiversity value of extensive green roofs (Madre et al., 2013). To address this question, we tested these hypotheses: (1) the type of aggregate in green roof growing substrate would affect plant establishment (abundance) and species richness; and (2) substrate depth would be important in determining plant diversity.

2. Materials and methods

Several recycled aggregates were chosen for this investigation and were supplied by Shire Green Roofs Substrates Ltd. (Southwater, West Sussex, UK), including: crushed red brick—typically used in extensive green roof substrate blends—and crushed yellow brick (both from defective house brick manufacture), clay pellets (containing sewage sludge and PFA), paper ash pellets (containing recycled newspaper 'ash'), Carbon8 pellets (containing limestone quarry waste and carbon dioxide) and Superlite (containing waste crushed aircrete). Full details of these aggregates are given in Molineux et al. (2009). The aggregates were used to create two green roof experimental test sites and the combinations of aggregates used are listed in Table 1. For all treatments, 75%/v aggregates were combined with 25%/v organics (50:50 blend of PAS100 compost and loam) to produce novel substrate blends. Where more than one aggregate was used, equal ratios of them were blended, e.g. 33.3% red brick, 33.3% clay pellets and 33.3% paper ash pellets then 75% of this mixed material combined with the same 25%/v organics. The amount of organics added to aggregates in this study was justified based on FLL Guidelines of ≤65 g/l (FLL, 2008), suggestions by Beattie and Berghage (2004) of between 10% and 25% organic matter and previous investigations by Molineux et al. (2009).

Table 1
The various substrate mixes for test plot I and test plot II.

Test plot	Substrate (treatment)	Substrate depth (cm)	Key
I	Clay pellets	5.5	C
I	Carbon8 pellets	5.5	8
I	Superlite mix	5.5	S
I	Red brick	5.5	R
I	Yellow brick	5.5	Y
I	Paper ash pellets	5.5	P
I	Red brick + clay pellets + paper ash pellets	5.5	RCP
I	Clay pellets + paper ash pellets	5.5	CP
I	Red brick + clay pellets	5.5	RC
I	Superlite mix + paper ash pellets	5.5	SP
II	Paper ash pellets	5.5	P1
II	Paper ash pellets	8	P2
II	Yellow brick	5.5	Y1
II	Yellow brick	8	Y2
II	Superlite mix	5.5	S1
II	Superlite mix	8	S2

2.1. Green roof experimental site

An experimental modular green roof was set up in May 2008 on the roof of the Bourne Laboratory (5 stories high) at Royal Holloway, University of London, Egham (Fig. 1). A series of prefabricated gravel trays (52 cm × 42 cm × 8 cm) were drilled with holes to allow for water drainage and lined with a filter membrane (ZinCo SF, ZinCo, Germany) to prevent particulate matter from washing into the drainage system. The experimental site was divided into two test plots (I and II) in order to investigate two variables: aggregate type and substrate depth respectively.

In test plot I, 50 trays contained 10 different substrate types; six was single substrates and four was of various combinations (Table 1). They were arranged in a randomized block design whereby each of the 10 substrates (treatments) appeared once per row and rows were replicated randomly, five times. Each tray was filled to 5.5 cm deep and seeded with 2.5 g of seed mix, equating to 10 g m^{-2} (Table 2). The amount of organics and seeds applied to each tray was kept constant, as was the depth of the substrates to ensure that the only variable in the experimental design was the type of aggregate. Watering came from rainfall alone (even throughout dry summer months) for a true representative, low-maintenance and extensive green roof situation. Because of this a high sowing rate of seeds was used. Previous research has found that if seeds are not watered initially for establishment (Monterusso et al., 2005), then a higher rate of sowing is required for increased individual numbers (Nagase and Dunnett, 2013).

In test plot II, there were 30 trays containing three substrates at two different depths (Table 1), 5.5 cm and 8 cm. Here, each of the six treatments was also replicated five times and seeded with 2.5 g per tray. The purpose of this test plot was to determine if substrate depth altered plant species richness and abundance within the same substrate type. Due to weight restrictions on the roof, only three aggregates could be tested, therefore substrates that had not performed as well in preliminary greenhouse trials (Molineux, 2010) were selected, to see if increasing depth could improve their performance.

2.2. Plant performance

In test plot I, plant surveys were conducted at six (November 2008), nine (February 2009) and fifteen (August 2009) months post-construction. As all plant species in seed mix were perennials, this allowed monitoring of establishment at end of year one and then overwinter and the summer of year two. On each date, the number of each plant species in each tray was recorded. Species identification followed Fitter et al. (1996). The survey of test plot II was conducted once, after 15 months.

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