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Characterising alternative recycled waste materials for use as green roof growing media in the U.K.

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ABSTRACT

We characterised four recycled materials that have been manufactured into useful substrates for use on extensive green roofs. These were a crushed red brick (the U.K. industry standard substrate base and therefore used as a control) and three alternative pellets made from: clay and sewage sludge (waste clay from excavations, fly ash and sewage sludge), paper ash (from recycled newspapers) and carbonated limestone (from quarry fines). Investigations into optimal organic content – conifer-bark compost for plant nutrients – and characterisations such as pH, particle size distribution, loose bulk density, particle density, XRF and leachate analyses were performed. Greenhouse experiments showed significant interactions between the four aggregates and the amount of added organic material, meaning that organic addition did not have the same effect on plant growth in each aggregate. The addition of organics also significantly reduced the pH of the recycled aggregates, making growing conditions for plants more favourable in these substrates. Particle density and loose bulk density results have shown all substrates to be classed as lightweight aggregates and leaching analysis has confirmed that all substrates perform within legal leachate limits for drinking water. As all the aggregates are commercially available at similar costs to the crushed red brick control, we believe that the alternative substrates have great potential in the green roof market and as they can be locally sourced we would also suggest that they are as good, if not better, than the industry standard, both economically and environmentally.

1. Introduction

Green roofs are generally classified into two types of systems: extensive and intensive. Intensive systems are more like roof gardens supporting large trees and shrubs, but requiring deep substrates and regular maintenance. Extensive systems are generally substrate-based with a vegetated layer or a *Sedum* mat, either on its own with a sponge membrane for moisture retention or with a substrate base; offering between 2.5 and 10 cm deep root zones due to restrictions by weight loading on a building's structure. In the U.K., substrate-based vegetated roofs concentrate on maximising biodiversity by encouraging plant species diversity (although there are all sorts of reasons for installing these types of roofs), whereas *Sedum* mat systems generally comprise only stonecrop plant species and are installed for clients wanting an instant 'green' effect. The purely substrate-based green roofs are relatively cheap to install compared to the *Sedum* systems, aim to recycle waste materials (such as broken bricks) and have been shown to support rare invertebrates and birds (Gedge and Kadas, 2005). They have predominantly been created using crushed brick or demolition waste, including crushed concrete as their substrate, in an attempt to mimic natural brownfield sites found in urban environments (Gedge, 2000; Grant et al., 2003). These 'brown' or 'biodiverse' roofs are usually constructed for this type of habitat mitigation in the U.K., especially in London, as the only litigation imposing constructors to install green roofs comes from the conservation of a rare bird species, the Black Redstart. This is a common species in many parts of Europe but in the U.K. it is a rare breeding species with most breeding sites at roof top level in large cities, especially London and Birmingham. Replacement of old buildings poses a direct threat to the species and as result habitat recreation is necessary to preserve the species (www.blackredstarts.org.uk).

In the U.K. sourcing substrates raw materials is challenging because crushed brick materials (as specified by the German FLL standards) are not always available within 50 km of the roof so long distance haulage is often necessary. Other potentially suitable materials are available, such as crushed demolition wastes, but these have to be processed in order to remove any nails or steel that may harm the roof waterproofing membranes, adding cost. Furthermore, alternative lightweight substrates for green roofs,

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such as LECA, Lytag, pumice and lava (Emilsson and Rolf, 2005) are generally manufactured overseas and are not locally available; thus varied green roof habitats for vegetation are not often possible. Therefore cost-effective, recycled, sustainable alternatives to crushed brick need to be found and assessed for use in the growing U.K. market (Fentiman and Hallas, 2006).

There has been very little biodiversity research conducted on green roofs in the U.K. Currently, unless there is the aforementioned compulsion to establish a green roof for black redstarts, architects and developers install green roofs for non-ecological reasons, such as aesthetical appeal, for green credentials and for economic value like thermal insulation and to reduce water run-off, as flooding is becoming increasing problematic in the U.K. (EA, 2003). For this reason they tend to use commercially available ready-made *Sedum* matting on very thin layers of substrate or directly onto a moisture mat; this generally does not allow natural plant colonisation nor offers the varied, species diverse environment that is desirable for most invertebrates that prefer deeper substrate bases (Gedge and Kadas, 2005; Kadas, 2007). Therefore most studies by green roof researchers seem to centre on water run-off quality and thermal properties provided by vegetated roofs. Water run-off quality is measured by the quantities of leachate contaminates, e.g. high phosphorus levels from too much organic fertilisation (Berndtsson et al., 2006; Emilsson et al., 2007). Studies have also been conducted to find out what effects substrate depth and roof slope have on water absorption and therefore quantities of run-off (Nicholaus et al., 2005), hydrological function (Bengtsson et al., 2005) and peak flows (Villarreal and Bengtsson, 2005). Thermal properties of green roofs (the vegetation layer) have been investigated and have revealed that the plants themselves reduce summer air temperatures significantly (Niachou et al., 2001), thereby emphasising the importance of vegetation cover. Life cycle assessments of vegetated buildings have also been conducted, concluding that energy costs can be greatly reduced by green roofs and that they can reduce the urban heat island effect (Booth, 2006; Saiz et al., 2006). These studies concentrate on economic benefits rather than biodiversity, but are nonetheless vital if green roofs are to become part of planning and development in the U.K. and other developed countries.

In this study we discuss the nature of the substrate, which is the basis of the entire green roof system. Guidelines have been produced for the green roof industry in Germany (FLL, 2002), however these standards are not always compatible with the U.K. market (e.g. they do not permit the use of recycled concrete or calcareous aggregates) and in these cases British standards have been followed. Relatively little has been published on alternative green roof growing media, especially from the U.K., and we believe that in order to achieve the desired green roof, an engineered substrate must be characterised. As substrate-based green roofs in the U.K. are generally for biodiversity (and *Sedum* roofs for economic and aesthetical appeal) it is important to determine if the alternative materials support vegetation in a similar or more successful way to the U.K. industry standard. This paper considers the following, 1) can recycled secondary materials support vegetation like a commonly used substrate in the U.K., and 2) are these recycled substrates viable alternatives in terms of material characterisations and economical costs.

This study has taken the U.K. green roof industry standard substrate of crushed red brick and compared it to three other recycled aggregates – all wastes that are usually sent to landfill – including: sewage sludge, waste clay, fly ash, paper ash and quarry fines. The sewage sludge waste is combined with locally sourced waste clay and fly ash from Tilbury, Essex and pelletised into usable lightweight aggregate by RTAL (Tilbury), hereafter termed 'clay pellets'. This company also manufactures waste paper ash pellets in a similar way, using ash produced by Aylesford Newsprint Ltd. (Aylesford, Kent) when recycling newspapers. These 'paper ash pellets' are lightweight and can be produced to varying sizes depending on their intended purpose. Finally, Carbon8 Contracting (Chatham, Kent) produce lightweight pellets from carbonating quarry waste (limestone based) by the use of waste carbon dioxide to improve structure and strength and to lower pH (Hills et al., 1999), hereafter termed 'carbon8 pellets'. Each of these aggregates is combined with an organic component, producing a substrate that can viably be manufactured at similar costs to the crushed red brick. In this study all four substrates have been characterised to further understand their potential as growing media for green roofs in the U.K. and although FLL guidelines have been considered, it was not always possible to relate findings to those in the standards due to the calcareous nature of the materials.

2. Materials and methods

2.1. Organic content

Before characterisation and trial experiments could begin, investigations were undertaken to establish the optimal amount of organics that should be added to the substrates, as a source of nutrients. Nutrients are required for healthy plant growth and as substrate-based green roofs should require very little maintenance, the right organic content in a substrate is vital if further fertilisation of the system is to be avoided (Emilsson et al., 2007). Commercially available top dressing compost was chosen, containing 50:50 conifer-bark compost and medium clay soil hereafter termed 'organics'. Seventy-two pots (8 cm height × 6 cm width) were set up in a greenhouse containing nine replicates of each aggregate (crushed red brick, clay pellets, paper ash pellets and carbon8 pellets) with 15% (by volume) organics and nine replicates with 25% organics. The greenhouse temperature ranged from 12 to 27 °C over the duration of the experiment and watering was given to all pots in equal amounts approximately every 2–3 days. The pots were sown with ten *Plantago lanceolata* (Ribwort plantain) seeds. *P. lanceolata*, a commonly used bait plant or phytometer (Bartelt-Ryser et al., 2005), was chosen to represent a wide range of plant species and it is often used in ecological experiments as it can withstand a wide range of pH values, is found pan-globally and can survive in all types of habitats; even harsh environments (Grime et al., 1988). After initial germination, seedlings were removed to leave three healthy individuals per pot, most of these seedling survived but in a few cases the replicate number was reduced due to mortality. Plant heights and total shoot biomass were measured for each pot after two months of growth.

2.2. Aggregate characterisation

2.2.1. pH values

The pH was determined for each aggregate and then each substrate (aggregate plus organic component). The first measurement was for the four aggregates where each had nine replicates. Thirty grams of material was soaked in 75 ml of distilled water for 24 h then three readings, using a HANNA HI 4521 pH meter, were taken for each sample to get an accurate mean for each of the replicates (as there can sometimes be small variations between readings). The second measurement was taken in the same way for the four substrates two months later, after plants were grown and subsequently harvested from the materials used in the greenhouse experiment (described in Section 2.1).

2.2.2. Particle size distribution

The particle size distribution within batches of different materials (aggregate with no organics added) was determined using BS