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The water retention capabilities of growing media for green roofs

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ABSTRACT

Green roofs can help reduce the risk of peak water flow and flooding in urban areas by reducing the amount impermeable surfaces on built land. This paper examines the contribution of growing media composition and depth to the water retention capabilities of green roof systems. Green roof simulation decks (decks) 1 m × 1 m were filled to a depth of 75 mm with growing media made with coarse crushed brick, coarse crushed tile or Lytag® amended with 10% (v/v) or 20% (v/v) composted green waste and planted with sedums (sedum decks); or to a depth of 150 mm with growing media made with fine crushed brick, fine crushed tile or Lytag® amended with 20% (v/v) or 30% (v/v) composted green waste and planted with flowering meadow plants (meadow decks). Growing media composition affected water holding capacity which in turn influenced water retention on the decks. The results indicated that both intra-particle pore spaces and inter-particle pore space distribution which was determined by particle size distribution were important determining factors of both water holding capacity and rainwater retention.

1. Introduction

Jha et al. (2012) state that in the last 20 years flooding, the most frequent form of natural disaster, has increased significantly worldwide. In urban areas, the prevalence of permanent structures and impermeable surfaces (FLUFP, 2010) create particular problems with peak water flow and flooding by increasing water flow beyond the level that can always be managed by traditional drainage systems (POST, 2007). It is estimated that nearly 6% of land in England is developed with domestic or non-domestic buildings, roads, rail or paths. Of this land approximately 2% is covered by buildings (FLUFP, 2010). Both the amount of land which is urbanised (Morton et al., 2011) and the density of dwellings in urban areas (FLUFP, 2010) are increasing. Precipitation has increased during the 20th century by 5–10% over the mid and high latitudes of Northern Hemisphere continents with a 2–4% increase in the frequency of heavy precipitation (50 mm in 24 h) in these areas (Gitay et al., 2002). Combined with the increases in urban dwelling and non-permeable urban land surfaces, both the risk and the potential severity of urban flooding are significantly increased.

The UK Environment Agency has developed a policy to encourage sustainable urban drainage systems which mimic natural drainage patterns so that the speed and volume of rainwater runoff in urban areas are reduced (Prosper, 2002). The aim of the sustainable urban drainage systems policy is that effective control of runoff at source using multiple small and discrete strategies can reduce the risk of downstream flooding (Woods-Ballard et al., 2007). Green roofs are just one of the potential strategies that could be used within the system and work by increasing the proportion of permeable surfaces that can retain and detain rain water. The use of green roofs may become increasingly important as the density of urban dwellings increases (FLUFP, 2010). Unlike many ground level sustainable drainage strategies, green roofs require no additional land beyond the footprint of the building to implement them (Woods-Ballard et al., 2007). To assess their value to the sustainable urban drainage systems strategy, however, it is necessary to quantify the water retention capabilities of green roofs.

The German roof greening guidelines indicate that the main source of variation in the water retention capabilities of green roofs comes from the depth of the growing media (FLL, 2008). Reference values for annual water retention range from 40% for an extensive green roof with 20 mm of growing media to more than 90% for an intensive green roof with 500 mm of growing media. Extensive green roofs are designed to require little maintenance and have shallower growing media than intensive green roofs which can support a wider range of plants and require considerable maintenance. The maximum annual water retention for extensive and semi extensive green roofs is about 60% as the growing media should be no deeper than 200 mm to minimise effects on the supporting building's load bearing capacity (FLL, 2008). Research shows that changes in the depth of growing media between 20 mm and 200 mm, the range for extensive and semi-extensive green roofs,

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Table 1
Growing media applied to green roof simulation decks. Treatment codes are derived from the initials of the vegetation type and inorganic material and from the proportion of inorganic material used.

Treatment code	Inorganic substrate	Particle Size (mm)	CGW particle size (mm)	CGW amount (% v/v)	Growing media depth (mm)	Vegetation
SB90	Coarse crushed brick	14–5	25–10	10	75	Sedum
ST90	Coarse crushed tile	15–6	25–10	10	75	Sedum
SL90	Lytag®	8–4	25–10	10	75	Sedum
SB80	Coarse crushed brick	14–5	25–10	20	75	Sedum
ST80	Coarse crushed tile	15–6	25–10	20	75	Sedum
SL80	Lytag®	8–4	25–10	20	75	Sedum
MB80	Fine crushed brick	5–2	10–0	20	150	Meadow
MT80	Fine crushed tile	6–0	10–0	20	150	Meadow
ML80	Lytag®	8–4	10–0	20	150	Meadow
MB70	Fine crushed brick	5–2	10–0	30	150	Meadow
MT70	Fine crushed tile	6–0	10–0	30	150	Meadow
ML70	Lytag®	8–4	10–0	30	150	Meadow

do not always result in appreciable changes in water retention capabilities. VanWoert et al. (2005) identified that the water retention capability of green roof simulation platforms was increased by increasing the depth of growing media from 25 mm to 40 mm, but the difference between the treatments was less than 3%. In contrast, Mentens et al. (2006) found in a meta-analysis of 18 green roof studies conducted in Germany that the average water retention as a percentage of total annual precipitation was 75% on intensive green roofs and 50% on extensive green roofs. The mean depth of growing media was 210 mm for intensive green roofs and 100 mm for extensive green roofs; however, other factors that may have influenced the water retention of intensive and extensive green roofs such as growing media composition were not reported. It is possible that growing media composition has a greater effect on a green roof's water retention capabilities than substrate depth, over the range of depths normally associated with green roofs. Growing media for intensive green roofs is not only deeper but tends to have a higher proportion of particles smaller than 1 mm and more organic matter (FLL, 2008). These factors are likely to increase the water holding capacity of the growing media (Fonteno, 1993), leading to better retention of rain water. Furthermore, Nagase and Dunnett (2012) found that the amount of runoff from green roof simulation trays decreased by between 23% and 38% when planted with forbs or grasses instead of sedums. Therefore, differences in planting between extensive and intensive green roofs may have also contributed to variations in water retention observed in meta-analysis (Mentens et al., 2006).

Bengtsson (2005) showed that runoff from an experimental green roof plot was only initiated once the water holding capacity of the growing media had been reached. The depth of water that the experimental plot could retain corresponded to the available water capacity which was determined as the difference between water holding capacity and permanent wilting point for the depth of growing media that was present. The available water capacity was approximately 30% (v/v) and the 30 mm of growing media was, therefore, able to retain up to 9 mm of water. If the growing media had been deeper the depth of water retained could have increased even though the available water capacity was the same. Even so, deeper growing media may not have significantly improved the annual water retention in their experiment because rainfall rarely exceeded this level. VanWoert et al. (2005) attempted to determine the effect of the depth of rain in a single event on green roof water retention. The water retention performance of green roof simulation platforms with growing media depth of 20 mm was as high as 96% following light rain events in which less than 2 mm rain fell but following heavy rain events in which more than 6 mm rain fell, the water retention performance was only 52%. Following the example of Bengtsson (2005), if the water holding capacity of the growing media was 20% (v/v), 30 mm of growing media would have been required to retain a 6 mm rainfall event. The depth required would increase to 60 mm if the water holding capacity were 10% (v/v). Schroll et al. (2011) also noticed that rain intensity could affect the water retention performance of test decks. They categorised rain events into those occurring during the wet season and those occurring during the dry season. The test decks retained 65% of the rain falling directly on their surfaces in the dry season but only 26% of the rain falling directly on their surfaces in the wet season.

There have been studies which have investigated the effect of growing media depth (VanWoert et al., 2005), rainfall intensity (Schroll et al., 2011) and available water capacity (Bengtsson, 2005) on the water retention capabilities of green roofs. However, the effect of growing media composition on the water retention capabilities of green roofs has received less attention. This study was undertaken to demonstrate the influence of growing media characteristics on water retention. It investigated the effect of the type of inorganic substrate and the amount of composted green waste in growing media on water retention of green roofs by measuring the amount of runoff from green roof simulation decks subjected to naturally occurring rainfall from December 2009 to June 2010 in the UK. The following null hypothesis was tested:

- Growing media depth, water holding capacity, inorganic substrate type and amount of composted green waste have no effect on the cumulative water retention capabilities of green roofs.

2. Materials and methods

Green roof simulation decks (decks) were prepared for this study in October 2009. In total, 36 decks were placed on timber frames 600 mm from ground level. The decks were 1000 mm (wide) × 1000 mm (deep) × 200 mm (height) and constructed by Wrexham Plastics Company Ltd., Wrexham using 9 mm thick polypropylene sheets. Each deck had a 20 mm wide drainage gap between the base and one side. A geotextile fabric placed over the drainage gap prevented materials from being washed away. A gutter was installed below the drainage gap with a garden hose inserted to allow the rainfall runoff to be collected in a 10 L plastic container for subsequent measurement. A one degree slope towards the drainage gap end was provided. The study was conducted at Harper Adams University, Shropshire between 9th December 2009 and 12th June 2010.

2.1. Growing media

Inorganic substrate was mixed in a 150 L capacity cement mixer with composted green waste to make the growing media. The inorganic substrates used in the sedum growing media were coarse crushed brick obtained from Hanson Ltd., Yorkshire; coarse crushed