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Developing resilient green roofs in a dry climate

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HIGHLIGHTS

- Intensive beds with media type B or C and a mild or steep slope performed best.
- *C. apiculatum* and *D crassifolium* performed better than *B multifida.*
- *D crassifolium* gave more cover and *C. apiculatum* taller, better surviving plants.
- Plants did not grow in media type A.
- Media type C showed superior water use efficiency.

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ABSTRACT

Living roofs are an emerging green infrastructure technology that can potentially be used to ameliorate both climate change and urban heat island effects. There is not much information regarding the design of green roofs for dry climates and so the aim of this study was to develop low maintenance and unfertilized green roofs for a dry climate. This paper describes the effects of four important elements of green roofs namely slope, depth, growing media and plant species and their possible interactions in terms of plant growth responses in a dry climate. Sixteen medium-scale green roofs were set up and monitored during a one year period. This experiment consisted of twelve vegetated platforms and four non-vegetated platforms as controls. The design for the experiment was a split–split-plot design in which the factors Slope (1° and 25°) and Depth (100 mm, 300 mm) were randomized to the platforms (main plots). Root depth and volume, average height of plants, final dry biomass and ground cover, relative growth rate, final dry shoot–root ratio, water use efficiency and leaf succulence were studied during a twelve month period. The results showed little growth of the plants in media type A, whilst the growth was significant in both media types B and C. On average, a 90% survival rate of plants was observed. Also the growth indices indicated that some plants can grow efficiently in the harsh environment created by green roofs in a dry climate. The root growth pattern showed that retained water in the drainage layer is an alternative source of water for plants. It was also shown that stormwater can be used as a source of irrigation water for green roofs during six months of the year at the study site. In summary, mild sloping intensive systems containing media type C and planted with either *Chrysocephalum apiculatum* or *Disphyma crassifolium* showed the best performance.

1. Introduction

One of the most serious challenges for sustainable urban development globally is climate change. This has also been one of the greatest concerns for communities and is consequently being investigated by several national, regional and global institutions and organisations (WMO, 2007). Relatedly, cities and their residents are key drivers of global climate change (Girmmond et al., 2010). Greenhouse gas emissions, including carbon dioxide, have been increased dramatically by urban development and greater use of fossil fuels, which in turn has led to reduced air quality and changed atmospheric cycles. Also urban development has increased imperviousness in the urban environment. This coupled with the common use of low albedo materials such as asphalt brings more serious environmental problems such as flooding and urban heat island effects (Carter, 2011). One of the best solutions for societies is to manage climate change through adaptation. This involves adapting both natural and human systems to respond to climate change and its effects (IPCC, 2007). However, a city's natural and built environment has a specific capacity for adaptation and also there are some risks associated with some adaptation techniques. An effective technique is to increase the proportion of green spaces and green infrastructure in urban areas (Benedict and McMahon, 2002; Gill et al., 2007;

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Carter, 2011). This can involve new stormwater management strategies such as Low Impact Development (Roy et al., 2008; Voyde et al., 2010), Sustainable Urban Drainage Systems (SUDS) (Carter, 2011; Stovin et al., 2013), Low Impact Urban Design and Development (LIUDD) (Van Roon, 2005) and Water Sensitive Urban Design (WSUD) (Kazemi et al., 2011; Beecham and Chowdhury, 2012). Examples of green infrastructure include green roofs, green walls, bioretention systems, swales, park lands and permeable and porous pavements. By adding green infrastructure to the urban environment, ecological functionality can be recovered (Francis and Lorimer, 2011). Approximately 20–40% of the impervious area in an urban environment is generally occupied by conventional roofs (Carter and Jackson, 2007; Kingsbury and Dunnett, 2008). A roof is the first surface that receives precipitation, which highlights the potential of green roofs in an urban environment to be one of the most important types of green infrastructure for source control. Several other environmental benefits of green roofs have been reported by Berardi et al. (2014). Green roofs can also reduce energy consumption by decreasing cooling and heating loads (Wong et al., 2003; Alexandri and Jones, 2008), provide amenity and aesthetic value (Razzaghmanesh et al., 2012; Fernandez-Cañero et al., 2013), increase building values (Nagase and Dunnett, 2010), improve stormwater runoff mitigation (Mentens et al., 2006; Voyde et al., 2010), lower air temperatures, enhance urban air quality (Feng et al., 2010), assist in urban stormwater pollutant removal (Berndtsson et al., 2006; Berndtsson, 2010; Razzaghmanesh et al., 2014b), reduce noise in urban environments (Dunnett and Kingsbury, 2004) and mitigate urban heat island effects (Wong et al., 2003; Castleton et al., 2010; Coutts et al., 2013). A green roof is a multi-layered engineered structure with a vegetated upper surface. Green roofs are normally categorized as either extensive (depth = 100 mm to 250 mm) or intensive (depth ≥ 300 mm) (FLL, 2002; Berndtsson, 2010). Selecting and optimising each green roof layer are the most important design issues. In a dry climate such as South Australia, designers often have to rely on standards and scientific data developed from work undertaken in northern hemisphere countries and this has been described by Williams et al. (2010b) as being a major barrier for developing a green roof industry in Australia. Other barriers include the high initial cost of installation, a lack of demonstration sites, the highly variable rainfall patterns across Australia, and the uniqueness of its vegetation. Most of the research in Australia has been undertaken on extensive green roofs. Results of early research in this sort of climate indicated that extensive green roofs provide very difficult growth conditions for plants (Durhman et al., 2004). This is because plants selected for green roof systems must be able to tolerate increased wind velocities, sun exposure, extreme heat, drought conditions and shallow root depths. To further explore the effect of climate in green roof systems in Australia, recent studies have been initiated mainly in the east and south east of Australia (Williams et al., 2010a,b; Farrell et al., 2012). These studies have mainly been conducted under controlled laboratory scale conditions and have generally concluded that for plants to thrive in such environments, they must be adapted to survive in dry conditions. Also no research studies have yet been conducted on the performance of intensive green roofs in dry climates. Therefore, an understanding of the relationship between water and plants and the effects of green roof materials is essential for developing sustainable green roof systems. Furthermore, considering that the maximum environmental benefits will be achieved from long-lasting green roof systems, this study is an extension of the work reported by Razzaghmanesh et al. (2014a) who investigated the performance of four prototype-scale experimental green roofs in Adelaide, South Australia. In this paper, the effects of roof slope, depth, growing media and plant species and their possible interaction on associated plant responses were investigated using sixteen green roof platforms. From the results of this study, the most appropriate and optimum combinations of the examined factors are recommended for designing resilient green roofs for a dry climate.

2. Materials and methods

2.1. Study site

The study area was in the suburb of Mawson Lakes (34.48° S, 138.37° E), which is located approximately 12 km north of the Adelaide Central Business District (CBD) in South Australia. Adelaide has a hot Mediterranean climate based on the Köppen–Geiger climate classification. This generally means that it has mild-wet winters and hot-dry summers. Rainfall is generally infrequent, light and unreliable throughout summer and the average precipitation in both January and February is approximately less than 20 mm. In winter, rainfall is much more reliable with June being the wettest month of the year, with approximately 80 mm of rainfall. In summer, the average maximum temperature is 29 °C but there is considerable variation in temperature and in the metropolitan area of Adelaide, there is usually more than a week every year when the daytime temperature is 40 °C or above (Sturman and Tapper, 2006).

2.2. Experimental setup

The experiment was conducted in sixteen small-scaled green roof systems (Fig. 1-A) constructed at the University of South Australia's Mawson Lakes campus. This experiment was monitored from early November 2012 until the end of November 2013 (Fig. 1-B & C). Four factors are investigated in the experiment. The first is slope for which the selected values were 1° (representing a mild slope) and 25° (representing a steep slope) to cover the range of the slopes described in the literature by Vilareal and Bengtsson (2005) and Gettera et al. (2007). The second factor is Depth for which depths of 100 mm and 300 mm were selected to represent extensive and intensive profiles, respectively (Williams et al., 2010a,b; Dunnett and Kingsbury, 2004). The third factor is species, which is based on three plant species, namely P1 — *Brachyscome multifida* (cut-leaved daisy), P2 — *Chrysocephalum apiculatum* (everlasting yellow buttons), and P3 — *Disphyma crassifolium* (round-leaved pigface), as described in Table 2. These were selected by reviewing the recommended native Australian plants for green roofs described by Hopkins and Goodwin (2007) together with consideration of the availability, sizes, health, maintenance, fire risk and adaptability to the local climate. The fourth factor is media for which types A, B and C were chosen, where:

- Media type A contained red crushed brick, scoria, coir fibre and composted organics;
- Media type B comprised scoria, composted pine bark and hydro-cell flakes; and
- Media type C contained 50% of media type B with the addition of 50% organic compost.

The composition and physico-chemical properties of the green roof growing media are described in Table 1. Media types A and B were sourced from an Australian supplier. Media type C was developed as local media, after a series of laboratory tests considering the FLL (2002) guideline recommendations, including water holding capacity, grain size distribution, and dry and wet bulk densities. The platforms were set up with two different slopes, namely 1° (representing a mild slope) and 25° (representing a steep slope).

The design for the experiment was a split–split-plot design in which the factors of slope and Depth were randomized to 12 platforms (main plots) so that each combination occurs on 3 platforms. Each platform was split into 3 areas (subplots) and media types randomized to the areas within a platform; each of these areas was filled with the assigned media type. Also, each area was split into 3 (sub-sub) plots and species randomized to the plots within an area. In addition to the twelve vegetated platforms, there were four non-vegetated platforms as controls. Furthermore, a drainage point was placed at the bottom of each area of a main platform which was connected through a pipe to an individual container so that the outflow water could be collected for measuring the drainage volume and for taking water samples. Basically the design of