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The growth and survival of plants in urban green roofs in a dry climate

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HIGHLIGHTS

- Biotic and abiotic indicators were used to assess the performance of plants.
- Supplementary irrigation was avoided by selecting appropriate plant species.
- All plants survived in intensive systems that contained a crushed brick mixture.

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ABSTRACT

Green roofs as one of the components of water-sensitive urban design have become widely used in recent years. This paper describes performance monitoring of four prototype-scale experimental green roofs in a northern suburb of Adelaide, South Australia, undertaken over a 1-year period. Four species of indigenous Australian ground cover and grass species comprising *Carpobrotus rossii*, *Lomandra longifolia* 'Tanika,' *Dianella caerula* 'Breeze' and *Myoporum parvifolium* were planted in extensive and intensive green roof configurations using two different growing media. The first medium consisted of crushed brick, scoria, coir fibre and composted organics while the second comprised scoria, composted pine bark and hydro-cell flakes. Plant growth indices including vertical and horizontal growth rate, leaf succulence, shoot and root biomasses, water use efficiency and irrigation regimes were studied during a 12-month period. The results showed that the succulent species, *C. rossii*, can best tolerate the hot, dry summer conditions of South Australia, and this species showed a 100% survival rate and had the maximum horizontal growth rate, leaf succulence, shoot biomass and water use efficiency. All of the plants in the intensive green roofs with the crushed brick mix media survived during the term of this study. It was shown that stormwater can be used as a source of irrigation water for green roofs during 8 months of the year in Adelaide. However, supplementary irrigation is required for some of the plants over a full annual cycle.

1. Introduction

Long-term temperature trends since the 1950s show that Australia's climate is warming and cool years have been rare in the last three decades. In particular, the last 10 years (2003–2012) remains one of Australia's warmest decades, with a temperature anomaly of +0.44 °C over the long-term average (Bureau of Meteorology, 2013). In recent years, green infrastructure has been seen as one of the most effective climate change adaptation tools (Carter, 2011). According to Benedict and McMahon (2002), in many North American cities, green infrastructure, including green roofs, permeable paving, vegetative swales, parks, woodlands, waterways and wetlands, can be used to promote ecological processes and improve the population's health and quality of life. In a recent study in South Australia, Ely and Pitman (2012) defined green infrastructure as a combination of green spaces and water systems that provide multiple environmental, social and economic benefits and services to urban communities. This includes green roofs and green walls, parklands, bioretention systems, swales, parks and reserves, backyards and gardens, waterways and wetlands, streets and transport corridors, pathways and greenways and sports fields. Health, liveability and sustainability of urban environments can be secured by developing effective green infrastructure. In addition, current and future risks associated with urbanisation growth, health, climate change and biodiversity loss will be remarkably decreased if we are able to develop sustainable and resilient cities. Green infrastructure tries to return urban environments to the ecological functionality that existed before urbanization (Palla et al., 2010). Approximately 20%–30% of the impervious area in an urban environment is generally occupied by conventional roofs (Carter and Jackson, 2007; Kingsbury and Dunnett, 2008). This highlights the potential of green roofs in an urban environment to be one of the most important types of green infrastructure. Green roofs can provide amenity and aesthetic value (Getter and Rowe, 2006; Razzaghmanesh

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et al., 2012; Jungels et al., 2013), increased building value (Nagase and Dunnett, 2010), stormwater runoff mitigation (Mentens et al., 2006; Durhman et al., 2007; Voyde et al., 2010), urban stormwater pollutant removal (Berndtsson et al., 2006; Berndtsson et al., 2009; Berndtsson, 2010; Razzaghmanesh et al., 2014), noise reduction (Dunnett and Kingsbury, 2004) and mitigation of urban heat island effects (Wong et al., 2003; Castleton et al., 2010; Chang et al., 2011). A green roof is an engineering multi-layered 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 optimizing each green roof layer is one of the most important design issues. In Australia, designers often have to rely on standards and scientific data from work undertaken in northern hemisphere countries and this has been described by Williams et al. (2010a, 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. Early research in Australia 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, 2010b; Farrell et al., 2012). These studies, which have mainly been conducted under controlled laboratory scale conditions, have generally concluded that for plants to thrive in such environments, they must be adapted to survive in dry conditions. Therefore, an understanding of the water and plant relationship is essential for sustainable green roof development. This is particularly important in Australian cities such as Melbourne, Adelaide, Perth and to a lesser extent Sydney, which have Mediterranean climates with extended periods of hot dry weather during the summer months. Of these cities, Adelaide in South Australia has a particularly high average inter-event dry period of 7 days in February compared to 5.5 days in Melbourne (Chowdhury and Beecham, 2010). Therefore, in this research, we investigated the key elements of a resilient green roof system for South Australian weather conditions by investigating plant performances in two different growing media types and depths using rainwater as the major irrigation source and supplementary irrigation whenever necessary. This has helped us to suggest the most suitable plant species and growing bed configurations for green roofs among those we have investigated in this experiment.

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), South Australia. It has a hot Mediterranean climate based on the Köppen–Geiger climate classification. This generally means it has mild-wet winters and hot-dry summers. Rainfall is generally infrequent, light and unreliable throughout summer, and the average precipitation in January and February is approximately 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 the 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 around a week every year when the day time temperature is 40 °C or above (Sturman and Tapper, 2006).

2.2. Green roof test beds

This study follows on from a previous investigation by Razzaghmanesh et al. (2014), which examined water quality changes in four green roof configurations located on a high rise building in the Adelaide CBD. The same-size green roof beds were constructed at the Mawson Lakes campus of the University of South Australia, located 12 km north of the CBD. This second investigation, which ran from February 2012 to March 2013, focused on plant performance. The experimental design consisted of four prototype-scale green roofs representing, two soil media depths and two media types. Details are provided in Table 1. All four green roof profiles included plants, growing media (or substrate), a geo-textile layer, a drainage layer, a protection mat and an underlying foam insulation layer to simulate the thermal conditions of a building roof structure. These layers were arranged on a timber frame table as shown in Fig. 1. To study the performance of plants in these green roof systems, four different native Australian plant species (Table 2) with four replications were planted. The composition and physico-chemical properties of the growing media are shown in Table 3. In construction of these green roof beds, all of the systems were lined and had a drainage collection point to measure the outflow rates and also, each bed was divided into two sections from the middle of the bed. The aim was to study two different watering treatments: (1) rainwater only and (2) rainwater plus supplementary irrigation. The irrigation practice was scheduled in <10 days intervals, and a volume of 20 L was applied each time according to local irrigation guidelines (SA Water Corporation, 2011). This supplementary irrigation was applied during 17 weeks of the study period.

2.3. Plant performance indicators

Plant height as a vertical growth index was measured in this study as one of the plant growth indices. This height was measured each time in relation to a fixed datum level for consistency of measurements (Nagase and Dunnett, 2013). Also, plant ground cover growth as a horizontal growth indicator was measured considering an equal radius from the centre of each plant and then the area of growth were calculated based on the circle shape and pattern of growth. Plant leaf succulence was determined according to Jones (2011) as the ratio of the water content of the leaf to the leaf's surface area. Twelve leaves from each plant of $P_{(1,1,1)}$–$P_{(1,4,16)}$ (see Fig. 1) and from each plot were sampled to determine leaf succulence. Leaf areas of individual leaves were measured using laboratory tools. Plant survival was also used as an indicator of plant performance and was measured as the number of days from the start of the experiment to complete plant die-off or to the end of the experiment (365 days for a 100% survival rate). Initial and final root and shoot biomasses after 12 months were also measured. At the start of the experiment, two plants from each species were selected, and these were used for measuring initial root and shoot biomasses. For each plant, the shoots and roots were separated, and the roots were washed on a sieve to prevent the loss of small roots. Then after separately

Table 1
Green roof bed configuration details.

Green roof bed	Media depth (mm)	Dimension (m × m)	Media type	Medium combinations	Plants
Extensive type A (EA)	100	1.50 × 1.20	Type A	Contained crushed red brick,	(1) *Carpobrotus rossii*, (2) *Lomandra longifolia* 'Tanika,'
Intensive type A (IA)	300	1.50 × 1.20	Type A	scoria, coir fibre and composted organics	(3) *Dianella caerula* 'Breeze,' (4) *Myoporum parvifolium*
Extensive type B (EB)	100	1.50 × 1.20	Type B	Scoria, composted pine bark and	
Intensive type B (IA)	300	1.50 × 1.20	Type B	hydrocell® flakes	