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Event size, substrate water content and vegetation affect storm water retention efficiency of an un-irrigated extensive green roof system in Central Texas

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ABSTRACT

As green roofs continue to grow in popularity more research will be needed in new ecoregions to support development of policy, regulation, and incentives. Extensive green roofs represent the majority of new construction each year and understanding their performance expectations is critical for regulation. In our experiment we tested the ability of three monocultures of low stature CAM plants (*Sedum kamtschaticum*, *Delosperma cooperi* and *Talinum calycinum* syn. *Phemeranthus calycinus*) to improve runoff reduction efficiency of un-irrigated modular extensive green roofs exposed to a range of precipitation event sizes in a warm and dry southern US climate. Stormwater runoff data were collected for 15 rainfall events that ranged from a minimum of 4.1 mm to a maximum of 102.9 mm. An average precipitation event retention efficiency of 78% was recorded. On average, the presence of *T. calycinum* enhanced retention efficiency by an additional 7.5% compared to unvegetated modules. Substrate volumetric water content affected retention capacity of unvegetated modules only.

1. Introduction

As green roofs increase in popularity due to the wide range of ecosystem services they provide (Carter & Jackson, 2007; Clark, Adriaens, & Talbot, 2008; Lundholm, MacIvor, MacDougall, & Ranalli, 2010; MacIvor, Ranalli, & Lundholm, 2011; Oberndorfer et al., 2007; Speak, Rothwell, Lindley, & Smith, 2012), the vast majority of new green roofs will likely be of the extensive type which are light-weight, shallow (2–12.7 cm), cheaper to build than intensive roofs and require minimal maintenance (Carter & Keeler, 2008; Kohler, 2004). Understanding their performance expectations is critical for regulation. Eleven North American cities already provide incentives or regulation including storm water management (GRHC, 2012). Maintenance practices for extensive green roofs range from little to no supplemental water and little to no fertilizer applications and weeding to frequent irrigation and application of fertilizer depending upon the green roof design and intent. In warm and dry climates, green roofs are often irrigated (Price, Watts, Wright, Peters, & Kirby, 2011; Simmons, Gardiner, Windhager, & Tinsley, 2008); however, maintenance can be reduced further if irrigation is only used during the plant establishment phase and not thereafter (Dvorak & Volder, 2013). Un-irrigated, shallow roof systems may provide greater stormwater benefits than irrigated roof systems as unused water storage capacity plays an important role in the retention rate (Jim & Peng, 2012; Stovin, 2010; Villarreal & Bengtsson, 2005).

Green roofs have been shown to be very effective at retaining stormwater, particularly when events are small (less than 10 mm) (Carter & Rasmussen, 2006; Getter, Rowe, & Andresen, 2007; Teemusk & Mander, 2007; VanWoert, Rowe, Andresen, Rugh, Fernandez, et al., 2005; VanWoert, Rowe, Andresen, Rugh, & Xiao, 2005). In addition to event size, retention efficiency also depends on slope, roof storage capacity (i.e., substrate water holding capacity and substrate depth) and how much of that storage capacity is already in use (Stovin, 2010; Villarreal & Bengtsson, 2005). Storage capacity usage is a function of time since last precipitation event, the size of that event and the rate of water loss from the system (drainage and evapotranspiration).

Although substrate depth, composition and drainage design are the most important determinants of water storage capacity (Morgan, Celik, & Retzlaff, 2013), vegetation of sufficient height and root mass can further reduce runoff (Dunnett, Nagase, Booth, & Grime, 2008). Dunnett et al. (2008) reported that increasing vegetative height improved precipitation interception, while greater root mass may have increased substrate water holding capacity by improving soil structure. In the same study, *Sedum* species were generally the worst performing plant species in terms of reducing runoff, both due to their generally low stature and low root mass. In contrast, VanWoert, Rowe, Andresen, Rugh, Fernandez, et al. (2005) and VanWoert, Rowe, Andresen, Rugh, and Xiao (2005) found that

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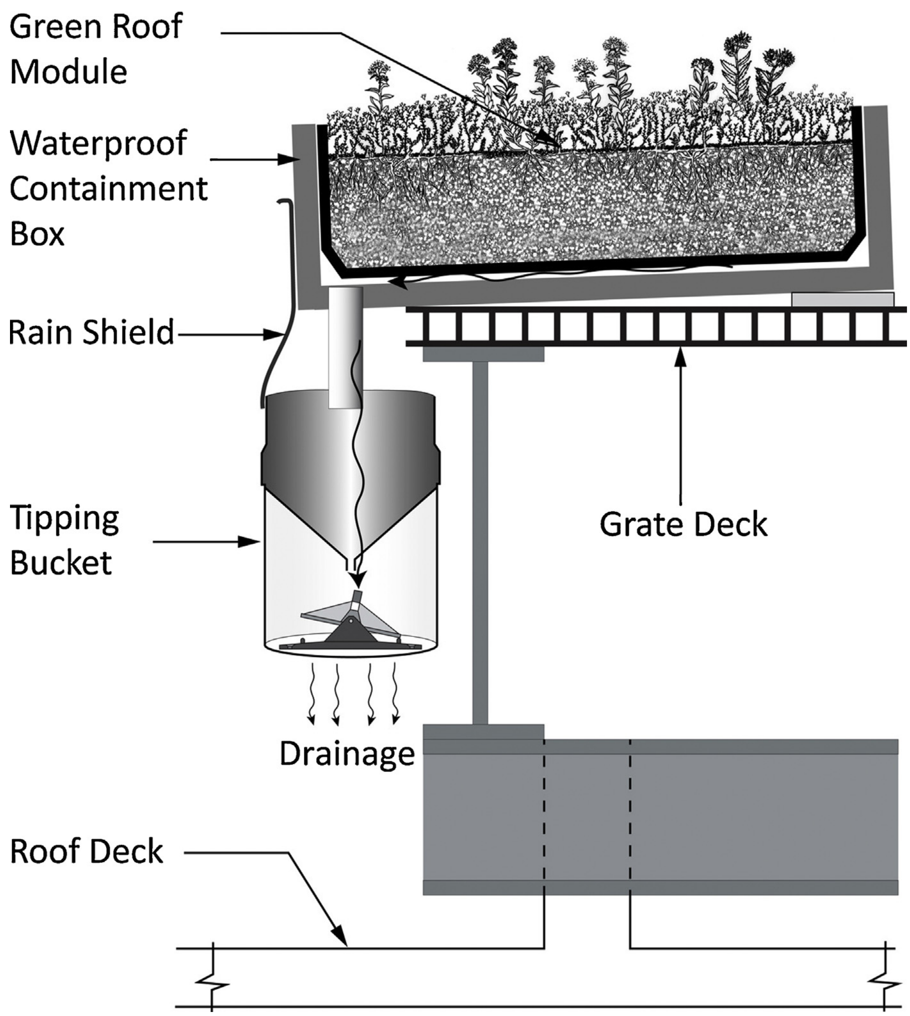

Fig. 1. Cross section of green roof module, waterproof containment box, rain shield, and tipping bucket.

Sedum species increased rainfall retention percentages of events >6 mm by 13.5% compared to substrate alone (52.4% versus 38.9% retention).

The ability of the vegetation to draw down substrate water content in between rainfall events through transpiration is generally a function of total leaf area, weather conditions (a high difference in vapor pressure between the air and the inside of the stomates enhances transpiration rates) and plant species (Lundholm et al., 2010; Voyde, Fassman, Simcock, & Wells, 2010). Succulent plants (such as *Sedum* species) are usually not the best choice of plants to achieve high rates of transpiration (Blanusa et al., 2013) since they generally have a low leaf surface area per unit mass (smaller thicker leaves) and may use a specialized photosynthetic pathway (CAM photosynthesis) where stomates are open at night instead of during the daytime. At night the vapor pressure difference between leaves and the air is strongly reduced compared to the daytime and thus transpiration rates are much lower. However, CAM plants such as *Sedum* and other succulent species are often the best choice for un-irrigated extensive green roofs due to their exceptional drought tolerance which allows them to survive and remain photosynthetically active under very challenging conditions (Durhman, Rowe, & Rugh, 2006; Gravatt & Martin, 1992; Thuring, Berghage, & Beattie, 2010; VanWoert, Rowe, Andresen, Rugh, Fernandez, et al., 2005; VanWoert, Rowe, Andresen, Rugh, & Xiao, 2005). It is essential to maintain a high cover of healthy plants as roof performance declines when vegetation is damaged (Speak, Rothwell, Lindley, & Smith, 2013). In this experiment the ability of monocultures of three succulent low stature species (*Sedum kamtschaticum*, *Delosperma cooperi* and a succulent indigenous to Texas *Talinum calycinum* syn. *Phemeranthus calycinus*) to improve runoff reduction efficiency was tested on un-irrigated modular extensive green roofs exposed to a range of precipitation event sizes in a warm and dry southern US climate.

2. Materials and methods

2.1. Experimental design

The research site was located in College Station, Texas on top of a four-story building at Texas A&M University. Stormwater runoff data were collected from twelve 11.4-cm-deep, 60 cm × 60 cm modular unirrigated green roof trays (TectaAmerica Corp, Skokie, IL). Each 0.36 m^2 plastic tray contained thirty-six 2.5 cm deep drainage retention cups filled with expanded shale to support the filter fabric and growing substrate above, covered with a non-woven moisture retention geotextile (filter fabric) and 8.9 cm of FLL (Forschungsgesellschaft Landschaftsentwicklung Landschaftsbau) compliant growing substrate for extensive green roofs (Rooflite® drain, Skyland USA LLC). The growing substrate filled the trays to the top of the module. Growing substrate specifications are a dry bulk density of 0.55–0.72 g cm^3, a bulk density at maximum water holding capacity of 0.70–0.95 g cm^{-3}, a total pore volume of ≥50%, a maximum water holding capacity after drainage of ≥15%,