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Solar radiation intensity influences extensive green roof plant communities

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Abstract

Two studies were conducted on a third-story rooftop to quantify the effect of solar radiation (full sun versus full shade) on several US native and non-native species for potential use on extensive green roofs. In the first study, plugs of six native and three non-native species were planted in May 2005 on substrates of two different depths (8.0 and 12.0 cm) both in sun and shade. Absolute cover (AC) was recorded using a point-frame transect during the growing season beginning in June 2005 and every 2 weeks thereafter for a period of 4 years. By week 174 (23 September 2008), most species exhibited different AC within a depth between sun and shade. However, when all species were combined, overall AC did not differ between sun and shade within a depth. This indicated that while species make-up was changing among solar radiation levels, that overall coverage was not significantly different between sun and shade. For all substrate depths and solar levels, the most abundant species were *Sedum acre*, *Allium cernuum*, *Sedum album* 'Coral Carpet', and *Talinum calycinum*. Less abundant species included *Talinum parviflorum*, *Carex flacca*, *Sedum stenopetalum*, and *Sedum divergens*, which all exhibited 0 or near 0 AC regardless of depth or solar radiation levels. With the exception of *T. calycinum*, native species were less abundant than non-native species.

In the second study, six common extensive green roof species of Sedum established from seed in May 2005 on a 10.0 cm (3.9 in) substrate depth were compared in both sun and shade over four growing seasons. AC was evaluated as in the previous study. Solar radiation did not affect AC, but overall species composition differed between sun and shade levels. The most abundant species in full sun were *S. acre* (0.57 AC) and *S. album* 'Coral Carpet' (0.51 AC). *Sedum kamtschaticum* (0.57 AC) and *Sedum spurium* 'Coccineum' (0.35 AC) performed the best in the shade. For both solar levels, the least abundant species at week 174 were *Sedum pulchellum* (0.0 AC) and *S. album* 'Coral Carpet' (0.1 AC).

Keywords: Eco-roof; Insolation; Native species; Stonecrop; Vegetated roof

Introduction

Green roofs, or vegetated roofs, are frequently installed in urban areas because of their ability to improve stormwater management (Carter and Jackson, 2007; Getter et al., 2007; Hilten et al., 2008; Jarrett and Berghage, 2008) and mitigate the urban heat island effect (Takebayashi and Moriyama, 2007). Green roofs provide many additional benefits as compared to traditional roofs including energy conservation (Santamouris et al., 2007; Sailor, 2008), increased longevity of roofing membranes (Kosareo and Ries, 2007), reduction in noise and air pollution (Van Renterghem and Botteldooren, 2008; Yang et al., 2008), increased urban biodiversity (Baumann, 2006; Brenneisen, 2006), as well as providing a more aesthetically pleasing living environment (Getter and

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Rowe, 2006; Oberndorfer et al., 2007). Recent research has suggested that green roofs are also a better return on investment than traditional roofs (Clark et al., 2008).

Green roofs are categorized as 'intensive' or 'extensive' systems. Intensive green roofs are designed to be similar to landscaping found at ground level, and as such require substrate depths greater than 15.0 cm and have 'intense' maintenance needs. In contrast, extensive green roofs use shallower substrate depths (less than 15.0 cm) and usually require minimal maintenance. Due to building weight restrictions and costs, shallow substrate extensive green roofs are much more common than deeper intensive roofs. Therefore, the focus of this paper is on extensive green roofs.

Plant selection for green roofs is often difficult due to the harsh urban environment and because plants are frequently subjected to extremes in temperature and drought due to their shallow substrate and elevation above ground. In addition, research involving plant selection thus far has typically been for roofs exposed only to full sun (Monterusso et al., 2005; Durhman et al., 2007; Getter and Rowe, 2008). However, as green roof implementation continues, it is likely that many green roofs will be shaded by other structures. Incoming solar radiation (insolation) directly and indirectly impacts plant growth and may depend on the species. In Utah, USA, high solar radiation zones differed from low solar radiation zones in terms of species performance (Dewey et al., 2004). Another study in the US Pacific Northwest looked at a sloped roof and found that in some cases the amount of solar radiation influenced plant performance (Martin and Hinckley, 2007).

Furthermore, overall climate and roof microclimate will determine plant success as well as the design intent for the green roof. A good example of this is the state of Florida's first pilot green roof installed in Naples, Florida, USA in 2003. The plant species chosen for this project were selected because of their green roof success in northern latitudes. But these species failed to survive in Florida's environment. The researchers concluded that plant selection was more important than other choices for green roof profile structure (Livingston et al., 2004).

Often clients desire the use of native species because of their real and perceived benefits, such as their longevity without the use of pesticides, fertilizers, or irrigation (EPA, 2008). While plants could not actually be native to rooftops, many plant species have evolved in extreme environments and are adapted to green roof conditions. However, native species are not necessarily more successful on green roofs than non-native species. Researchers in Michigan, USA evaluated 18 native taxa on unirrigated extensive green roof platforms (Monterusso et al., 2005; Rowe et al., 2005). After 3 years, only four of the species survived. The majority of the plants tested were considered to be drought tolerant, but their survival in a native environment relies on deep tap roots to obtain moisture. In a shallow extensive roof, these roots can still grow sideways, but periods of drought resulted in death. These plants may have all survived with deeper substrates or supplemental irrigation.

One technique used to assess plant stress in such harsh conditions is measurement of chlorophyll fluorescence. This technique is used to quantify the efficiency of the photosynthetic apparatus (Maxwell and Johnson, 2000). Photon energy absorbed by a chlorophyll molecule can be used to fuel photosynthesis, dissipated as heat, or re-emitted as fluorescence. Measurement of the latter is used to indicate how efficient the former two processes are proceeding. Fluorimeters are used to measure this value, usually reporting the ratio (F_v/F_m) of variable fluorescence (F_v) to maximum fluorescence (F_m) that typically range from 0.70 to 0.83, with values less than 0.60 indicating photosynthetic stress (Ritchie, 2006).

Many studies of plant survival on green roofs are based on 1–2 years data (Kircher, 2004; Emilsson and Rolf, 2005; MacDonagh et al., 2006; Durhman et al., 2007; Nagase and Dunnett, 2008). Since green roofs are estimated to last 45 years or longer in terms of mechanical lifespan (Kosareo and Ries, 2007), long-term plant performance beyond the first few years of establishment is important. Plants that survive initially on a green roof may not continue to exist in the long term because of variability in climate and other factors. Therefore, the objective of this study was to evaluate the effect of substrate depth and solar radiation intensities (full sun versus full shade) on substrate moisture, plant stress as measured by chlorophyll fluorescence, and plant community development of both US native and typical non-native green roof species in a Midwestern climate over a period of 4 years. In addition, a primary goal of this paper is to provide species recommendations for different rooftop environmental conditions.

Materials and methods

Green roof plots

Green roof plots were established on the Communication Arts building on the campus of Michigan State University in East Lansing, Michigan, USA in May 2005. This building was chosen because the roof is constructed such that it can easily accommodate varying substrate depths and it is tiered in such a way that approximately 10% of the roof is always in complete shade (defined here as the absence of direct solar radiation) from the upper building structure. Six wooden frames were built measuring 120 cm × 234 cm with sides of 15.2 cm in depth (Fig. 1). Each frame was