Greening Rooftops for Sustainable Communities
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Session 3.5: Options and Benefits: Learning from Case Studies

GREEN ROOF STORM WATER RETENTION - GETTING TO THE WEIGHT OF THE MATTER!

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Abstract

Green roof technology is increasingly used to aid in reducing urban storm water runoff. However, when the growth media becomes saturated it loses its ability to retain any further precipitation until some rainwater has evaporated or been transpired. A growing medium and plant species combination that loses the most water to the atmosphere following saturation will increase the storm water retention of the green roof. Our research includes twenty-four Green Roof Blocks™ and forty-eight Green Paks™, located on the SIUE Engineering Building Green Roof in Edwardsville, Illinois. These modular systems were placed in a completely randomized design with three replicates in May 2006. In this project we have evaluated four growth media types, the contribution of vegetation (roof coverage), and the contribution of a drainage layer to storm water retention and loss back into the atmosphere. Individual green roof systems were weighed for up to a week following saturation events from establishment in 2006 through September 2008. Significant differences were found for storm water loss to the atmosphere from the four growth media types and by drainage layer orientation. Green roof systems containing lava growth media lost (evaporated or transpired) the most storm water to the atmosphere. Our data clearly indicates that design choice impacts storm water retention and water loss through evaporation and transpiration by green roof systems.

Introduction

Storm water runoff has become an increasing environmental concern in urbanized and developing areas due to the large proportion of impervious surfaces. These surfaces are designed to remove water quickly during rain events, and result in increased storm water volume and peak flow rates (DeNardo et al., 2008) which can alter stream hydrology, channel morphology, and riparian communities (USEPA, 1999). In addition, the large volumes of storm water during a rain event may overwhelm combined sewer overflow systems and cause untreated sewage to be released into waterways (Kohler et al., 2001). Several best management practices (BMPs) and low impact development (LID) methods have been used to reduce runoff volumes and peak flows to storm water systems by promoting storm water retention, detention, infiltration and/or evaporation, reducing impervious surfaces, and increasing runoff time (e.g., green roofs, bioretention areas, grass swales, and pervious pavements) (USEPA, 1999; USEPA, 2000). However, some methods of storm water management such as large retention basins may be difficult and/or expensive to apply in the urban setting due to the limited space available. Functioning and design of many of these practices are influenced by site conditions such as soil permeability, slope, and water table depth (USEPA, 1999; USEPA, 2000). Green roofs can take advantage of otherwise unused roof area where space at ground level is limited, and reduce the amount of impervious surface in an urban area.

Green roof systems are able to decrease storm water runoff (Kohler et al., 2001), peak flows (Bengtsson, 2005; Moran et al., 2003), and delay runoff (DeNardo et al., 2003). Storm water retention by a green roof is dependent on the intensity and frequency of rain events (Carter & Rasmussen, 2006), climatic conditions (Mentens et al., 2005), vegetative composition (Dunnett et al., 2008), substrate moisture content at the start of a rain event (Monterusso et al., 2004), and media depth and slope (VanWoert et al., 2005). Once the growth medium is saturated with rainfall the retention of storm water goes down significantly. Several studies have demonstrated that storm water retention is greatest when the growth medium is dry (Bengtsson, 2005; Monterusso et al., 2004; Villareal & Bengtsson, 2005). The water retained by the growth media can potentially be lost between rain events through evaporative losses and by transpiration of water available to green roof plants. A study involving porous materials found that particle size and pore size were important to the rate of evaporation (Wanphen & Nagano, 2009). The growth medium composition can also be important in plant growth and success. Emilson (2008) found that substrate design and type are important for vegetative development on a green roof. Vegetative cover contributes to the aesthetic value of a green roof, and may be important in storm water retention and loss to the atmosphere through transpiration

Sedum spp. are a common group of plants selected for extensive green roofs, because of their ability to survive in the harsh environment found on these roofs. VanWoert et al., (2005) found that *Sedum* spp. used in their study were able to survive the 88 day experiment without water. Some individuals in the genus are known as C_3-CAM intermediates (Conti & Smirnoff, 1994; Sayed et al., 1994; Lee & Kim, 1994). They perform C_3 photosynthesis when water is readily available and CAM when water is limited. This could potentially allow for rapid water loss following a rain event, and allow the plants to reduce water loss from plant tissues during dry periods.

Rapid water loss through evapotranspiration would increase the capacity of a green roof to intercept additional storm water during the next rain event and keep it out of the municipal storm water system. Rapid water loss is especially important when there are short intervals between rain events. The green roof materials used could impact the overall evapotranspiration rate due to the different properties and characteristics each has. Therefore proper selection of growth medium and plant species combinations could optimize evapotranspiration from a green roof system.

Methods

Our research utilized two types of modular green roof systems (Green Paks™ and Green Roof Blocks™). On May 23, 2006 both green roof systems were transported to the Southern Illinois University Edwardsville Engineering Building Roof (Figure 1). Forty-eight Green Paks™ (polyethylene knit fabric, dimension 2' X 3') were filled to a depth of 10 cm with one of four types of growth media (three locally blended-media; Arkalyte-expanded clay, Hadite-expanded slate, and Lava, and Midwest Mix™ a proprietary media blend). Each locally blended growth media consisted of 80% inorganic and 20% composted pine bark. JDR drainage layers cut to the dimension of the Green Paks™ were placed under each Green Pak™. The drainage layer was either oriented with the 3/8" drainage cups up or cups down to evaluate storm water retention by the drainage layer. A metal rod was used to pass a 12' rope between the drainage cups down the length of a Green Pak™ and back. The ends of the rope were knotted, and used as handles to hoist the Green Paks™ to the balance when weighed. A gas torch was used to burn six holes slightly larger than a *Sedum kamtschaticum* plug in each of the Green Paks™. Half the Green Paks™ were planted with six *S. kamtschaticum* plugs per pak, and the other half contained no plants to evaluate plant contribution to storm water retention.

Twenty-four Green Roof Blocks™ (anodized aluminum, dimension 2' X 2') were filled with one of the same four types of growth media described above to a depth of 10 cm. Half the Green Roof Blocks™ were planted with five plugs of *S. kamtschaticum*, and the other half contained no plants. A walk pad material with adhesive back was cut into 2" X 2" squares, and placed under the four corners and middle of each Green Roof Block™. This provided a space between the block and the roof surface, and allowed water above field capacity to drain from the Green Roof Blocks™. Both the Green Roof Blocks™ and Green Paks™ were replanted with mixed *Sedum* spp. plugs in May 2007 due to high mortality of *S. kamtschaticum* plants.

Three replicates of both Green Roof Blocks™ and Green Paks™ were placed in a completely randomized design on the engineering building roof on May 23, 2006 (Figure 2). We then watered each green roof system until they were completely saturated using a garden hose with sprinkler head, and watered as needed over the next ten weeks to allow the plants to establish.

Plant coverage during the study period was quantified using a modified dot grid. The grid used for Green Roof Blocks™ was a 6 X 6 circle coverage grid (each circle is 3.8 cm in diameter), and covers one fourth of the block. The 6 x 6 circle coverage grid was placed in each quadrant of the block, and the number of circles with vegetation were counted and recorded. The number of circles with vegetation was divided by the total number of circles and multiplied by 100 to calculate percent coverage. The grid used for Green Paks™ was an 8 X 10 circle coverage grid, and covers one half of the pack. The 8 X 10 circle coverage grid was placed in each half, and percent coverage was recorded and calculated in the same way as for the Green Roof Blocks™. Plant coverage data closest to each year's weigh period are presented (10/05/06 and 11/20/08).

Water loss measurements began in September 2006 to allow sufficient time for the plants to establish, and contribute to water retention and evapotranspiration. An Ohaus DS20L balance was placed near the center of a replication on the roof surface to reduce transport distance while weighing. A 2' X 3' sheet of plywood was centered on top of the balance so that the whole Green Pak™ was supported, the balance was tared, and each green roof system was weighed.

We saturated the green roof systems with a hose and sprinkler head on 9/13/06, and then weighed each on 9/14/06. There was ~2in. rain event on 9/17/06 which saturated the media, and we weighed each roof system on 9/18/06, 9/20/06, and 9/21/06. We received more rain on 9/24/06, and weighed the mornings of 9/25/06, 9/27/06, and 9/29/06.

Green roof models were replanted with mixed *Sedum* spp. plugs in May 2007, and nearly reached full coverage by July 2008. We began weighing 7/15/08 after saturating with a hose and sprinkler on 7/14/08. We then weighed 7/16/08, 7/17/08, and 7/18/08. There was a rain event before the next weigh date on 7/22/08, and another rain event occurred after weighing on 7/24/08. The last interval measured included data collected on 7/31/08 and 8/01/08 which occurred following a rain event. Weight data is presented here from 9/18/06-9/21/06, and from 7/15/08-7/18/08.

Saturated weights from 7/15/08 and 9/18/06 (following significant rainfall events) were also used to estimate weight change of the green roof systems due to biomass increase, wind scour and/or organic matter breakdown and loss over the two year period.

To compare the total storm water loss from growth media and vegetation, a one-way ANOVA was used in a completely randomized design to test for significant differences between treatments. Then a Tukey's post-hoc test was used to rank differences at an alpha level of 0.05 (Proc GLM, SAS Version 9.1).

Results and Discussion

In Green Roof Blocks™ differences in storm water loss by media type were not significant for treatments with plants and without plants between 9/18/06-9/21/06 (Figures 3a and 3b). In Midwest Mix™ more water was lost from the planted treatment over this period, but the other three growth media types lost similar amounts of water between treatments with plants and without plants. Plant coverage was also significantly greater in Midwest Mix™ than the other three media types during this period (Figure 3c). It is important to note that percent roof coverage in the other three media types were all below 25%, and this may be why *S. kamtschaticum* did not contribute significantly to water loss for Arkalyte, Hadite and Lava (Figure 3c). In Green Roof Blocks™ differences in water loss by media type were also not significant in treatments with plants and without plants between 7/15/08-7/18/08 (Figures 4a and 4b). All four media types lost slightly more water in the planted treatment than the treatment without plants over this period. In a study by Wanphen and Nagano (2009), greater water loss also occurred from the media planted with *Sedum*. However their study also found differences in water loss among different porous materials, and this did not occur for media in the Green Roof Blocks™ modular system used in our study. Percent roof coverage of *Sedum* spp. in 2008 in the planted treatment of our study was greater than 65% in all media types, and likely accounted for the additional water loss to the atmosphere. Midwest Mix™ had significantly greater coverage than other media types with a mean greater than 90% coverage (Figure 4c). The differences in plant coverage by media type found in this study (Figures 3c and 4c) are consistent with the Emilson (2008) study where vegetative development was influenced by substrate type.

In Green Paks™ with drainage layer cups oriented up, differences in storm water loss by media type were significant for treatments with and without plants between 9/18/06-9/21/06 (Figures 5a and 5b). Wanphen and Nagano (2009) also found differences in water loss by media type with different physical properties and pore characteristics in their study. Water loss from GreenPaks™ with the same media type was nearly the same in the treatments with plants and without plants in 2006. Percent roof coverage was less than 26% in all media types at this time. Midwest Mix™ had significantly greater *S. kamtschaticum* coverage than Arkalyte and Hadite (Figure 5c). Percent roof coverage may have been too low for the plants to contribute significantly to water loss at this point. There were no significant differences in water loss from media type in treatments with and without plants over the period of 7/15/08-7/18/08 (Figures 6a and 6b). However, water loss from media with plants was greater than media without plants for all media types except Arkalyte where it was nearly equal. Percent roof coverage with mixed *Sedum* spp. was over 75% in all media types, but there were no significant differences in coverage between media type (Figure 6c).

In Green Paks™ with drainage layer cups oriented down, differences in storm water loss by media type were significant for treatments with and without plants over the period of 9/18/06-

9/21/06 (Figures 7a and 7b). Lava growth medium lost significantly more water than Midwest Mix™ and Arkalyte growth medium. Percent roof coverage was significantly greater in Lava growth medium and lowest in Arkalyte growth medium (Fig 7c). The greater water loss from Lava may have been due to the relatively high coverage in the planted treatment, and also due to the physical characteristics of the aggregate. Wanphen and Nagano (2009) found that the physical properties of porous materials were important to evaporation rates in their study. The Lava growth medium in our study has a very porous surface where water can accumulate after rainfall. This water may be more readily available to the plant, and may also enhance evaporative losses from exposed medium. There were no significant differences in water loss by media type in treatments with and without plants over the period of 7/15/08-7/18/08 (Figures 8a and 8b). Water loss was greater from planted treatments of Lava and Midwest Mix™ than from treatments without plants for these two growth medium, and nearly the same for Arkalyte and Hadite. Percent roof coverage with mixed *Sedum* spp. was over 85% in all media types, but there were no differences in coverage between media type (Figure 8c).

We compared saturated weights over two years by media type in both types of green roof modular systems. In Green Roof Blocks™ there were significant differences by media type in treatments with plants and without plants (Figures 9a and 9b). Weight gain over the two year period was significantly greater for Midwest Mix™, and the gain was also greater in the planted treatments. Midwest Mix™ had relatively greater coverage throughout the study, and plant coverage may help to reduce wind scour. The greater biomass in 2008 than 2006 may have accounted for the increase in weight as well. All media types lost weight in the treatments without plants, and the Arkalyte and Lava growth media lost the most weight over the two year period. This suggests that there was some wind scouring on the roof and possibly organic matter breakdown and losses.

In Green Paks™ there were significant differences in weight loss/gain by media type in treatments with plants and without plants. Weight gain over the two year period in the treatment with plants occurred for only the Midwest Mix™ growth medium (Figure 9c). In the Green Paks™ treatment without plants Arkalyte and Lava lost significantly more weight than other media types (Figure 9d).

The Green Roof Blocks™ lost more weight than Green Paks™ with the same media type for all but the Arkalyte growth medium in planted treatments (9a and 9c). In treatments without plants, the Green Roof Blocks™ lost more weight than Green Paks™ with the same media type for all media types (9b and 9d).The Green Roof Blocks™ have an open surface which may allow wind scour of growth media to occur when plant coverage is low. The Green Paks™ polyethylene knit fabric encloses much of the surface, and may help to reduce wind scour compared to the Green Roof Blocks™. Greater weight losses were found in treatments without plants than with plants for all media types in the Green Roof Blocks™. In the Green Paks™ greater losses were found in treatments without plants than with plants for all media except Arkalyte. This suggests that vegetative cover may help to reduce weight losses through wind scour and retention of fines and organic matter by plant roofs.

Conclusions

Our study shows that atmospheric water loss by green roof systems may be affected by growth medium type, plant coverage, and drainage layer orientation. There were no significant differences in water loss by media type in the Green Roof Blocks™ in either year. This modular system has anodized aluminum sides and bottom, and therefore only the surface is exposed to the environment. This may reduce evaporation differences among growth medium types. There were significant differences in water loss by media type in Green Paks™ for the year 2006. The polyethylene knit fabric may expose more of the media to the environment for evaporation, and may account for the differences in evaporation rates from growth medium type. Treatments with plants typically lost more or equal amounts of water to the atmosphere compared to the treatments without plants. Some exceptions occurred in 2006, but plant coverage was low at this time. Proper selection of green roof materials may optimize water loss through evaporation and transpiration by green roofs systems, and increase the roof's capacity for storm water retention of future rain events.

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Figure 1. Green Paks™ and Green Roof Blocks™ on the SIUE Engineering Building roof after installation on May 23, 2007.

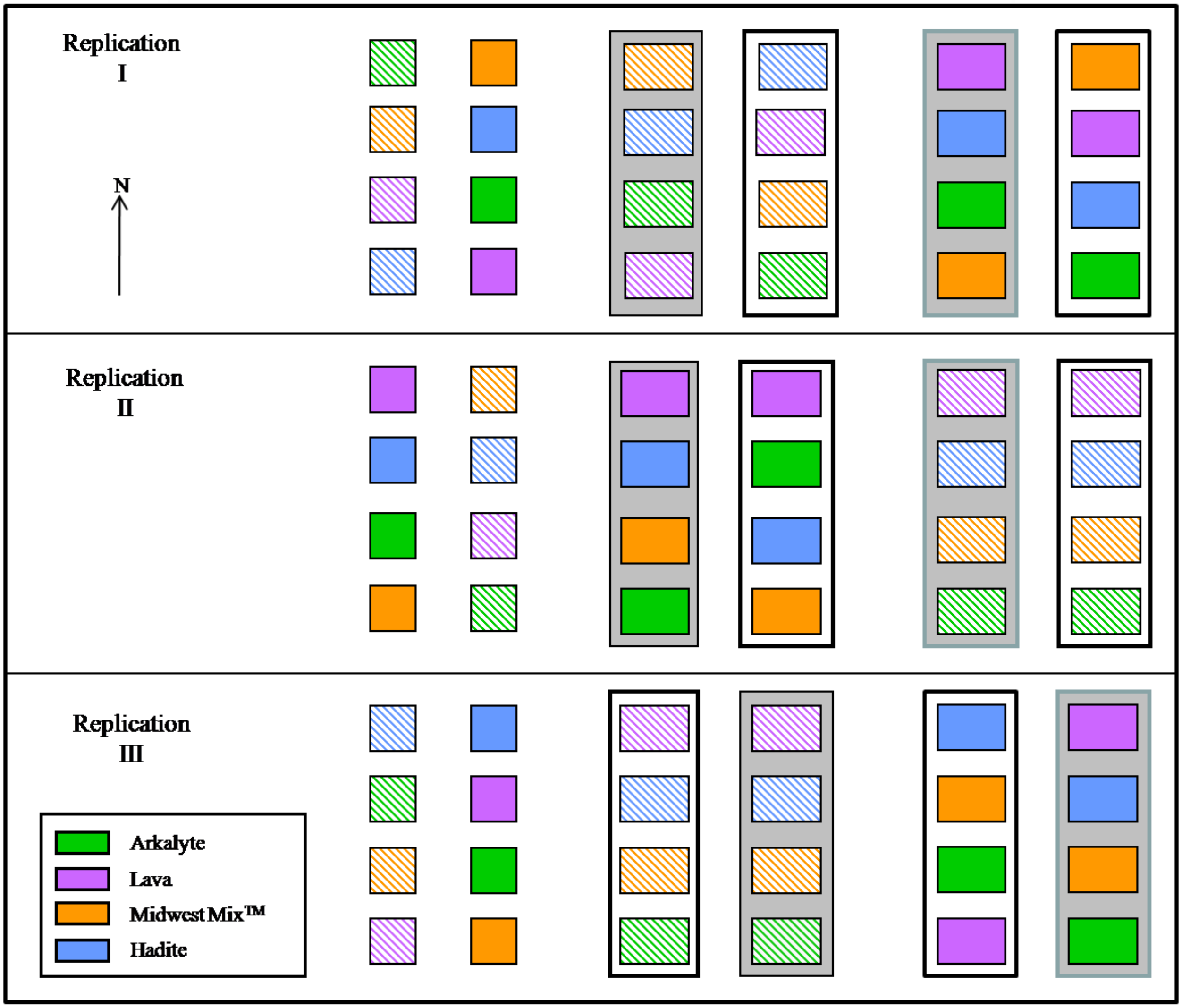

Figure 2. Green Paks™ (rectangles) and Green Roof Blocks™ (squares) placed in a completely randomized design on the Engineering Building roof at SIUE. Boxes with solid color contain media and plants, and boxes with diagonal lines contain only media. A grey box around a group of four represents a drainage layer with cups up, and a white box represents a drainage layer with cups down.

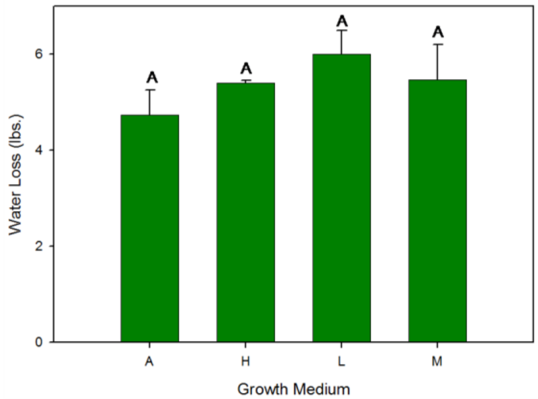

Figure 3a. Total water loss from Green Roof Blocks ™ with plants between 9/18/06-9/21/06. Bars with different letters are significantly different (α<0.05). Error bars represent plus one standard error. n=3 for all

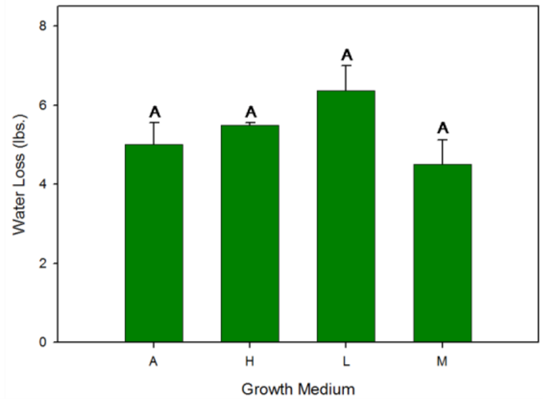

Figure 3b. Total water loss from Green Roof Blocks™ without plants between 9/18/06-9/21/06. Bars with different letters are significantly different (α<0.05). Error bars represent plus one standard error. n=3 for all.

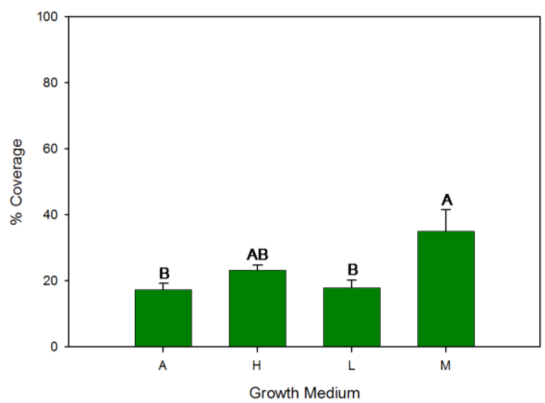

Figure 3c. Percent coverage of *S. kamtschaticum* plants in Green Roof Blocks™ on 10/05/06. Bars with different letters are significantly different (α<0.05). Error bars represent plus one standard error. n=12 for all.

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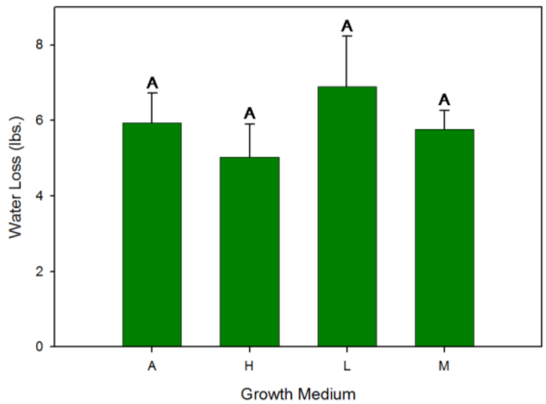

Figure 4a. Total water loss from Green Roof Blocks™ with plants between 7/15/08-7/18/08. Bars with different letters are significantly different (α<0.05). Error bars represent plus one standard error. n=3 for all

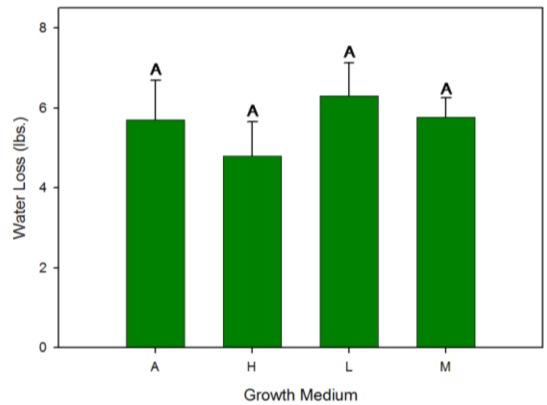

Figure 4b. Total water loss from Green Roof Blocks™ without plants between 7/15/08-7/18/08. Bars with different letters are significantly different (α<0.05). Error bars represent plus one standard error. n=3 for all

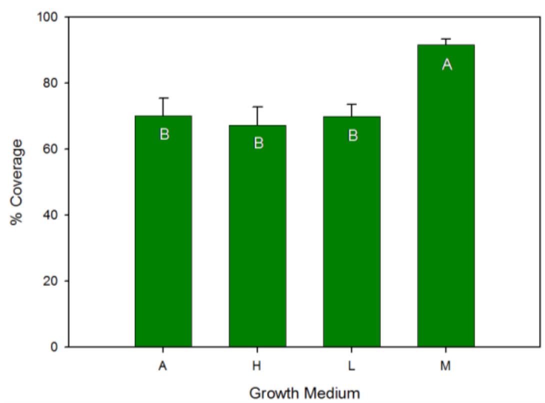

Figure 4c. Percent coverage of mixed *Sedum* spp. in Green Roof Blocks™ on 11/20/08. Bars with different letters are significantly different (α<0.05). Error bars represent plus one standard error. n=12 for all.

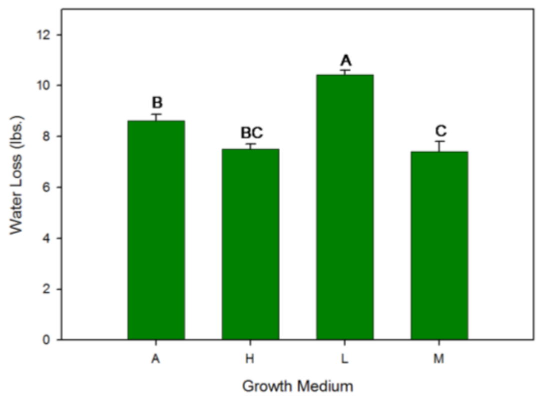

Figure 5a. Total water loss from Green Paks™ with plants and drainage layer oriented with cups up between 9/18/06-9/21/06. Bars with different letters are significantly different (α<0.05). Error bars represent plus one standard error. n=3 for all

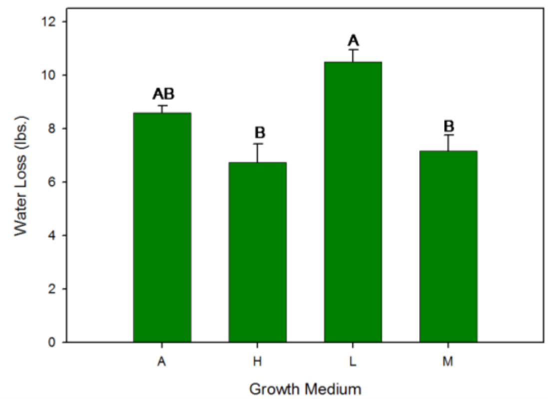

Figure 5b. Total water loss from Green Paks™ without plants and drainage layer oriented with cups up between 9/18/06-9/21/06. Bars with different letters are significantly different (α<0.05). Error bars represent plus one standard error. n=3 for all

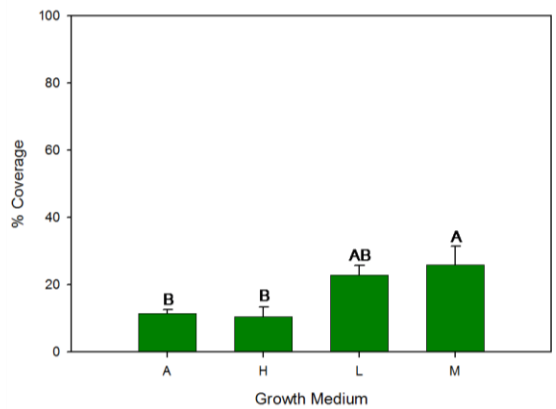

Figure 5c. Percent coverage of *S. kamtschaticum* in Green Roof Blocks™ with drainage layer oriented with cups up on 10/05/06. Bars with different letters are significantly different (α<0.05). Error bars represent plus one standard error. n=12 for all.

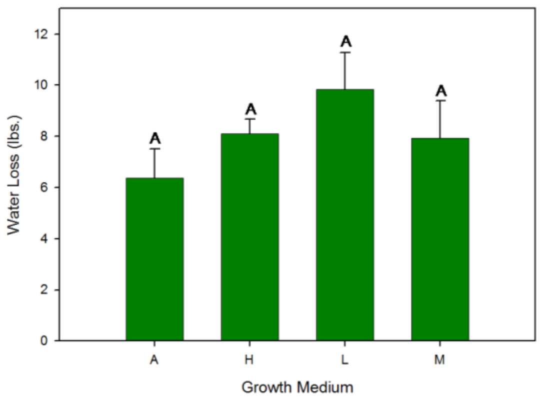

Figure 6a. Total water loss from Green Paks™ with plants and drainage layer oriented with cups up between 7/15/08-7/18/08. Bars with different letters are significantly different (α<0.05). Error bars represent plus one standard error. n=3 for all

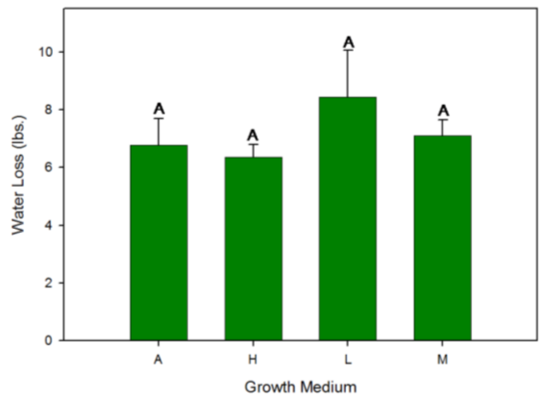

Figure 6b. Total water loss from Green Paks™ without plants and drainage layer oriented with cups up between 7/15/08-7/18/08. Bars with different letters are significantly different (α<0.05). Error bars represent plus one standard error. n=3 for all

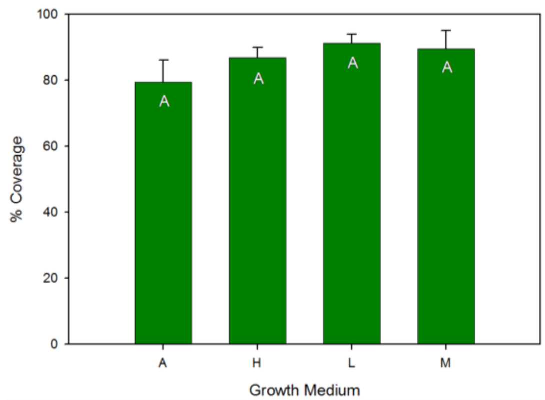

Figure 6c. Percent coverage of mixed *Sedum* spp. in Green Paks™ with drainage layer oriented with cups up on 11/20/08. Bars with different letters are significantly different (α<0.05). Error bars represent plus one standard error. n=12 for all.

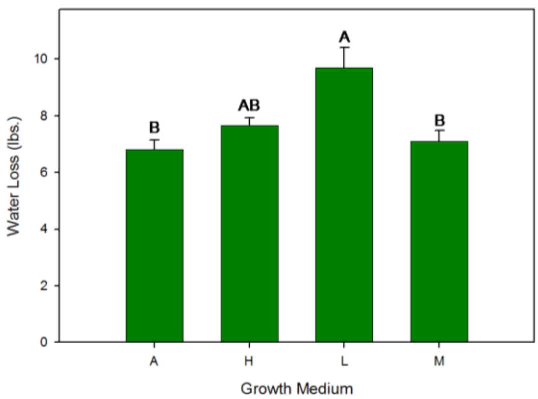

Figure 7a. Total water loss from Green Paks™ with plants and drainage layer oriented with cups down between 9/18/06-9/21/06. Bars with different letters are significantly different ($\alpha<0.05$). Error bars represent plus one standard error. n=3 for all

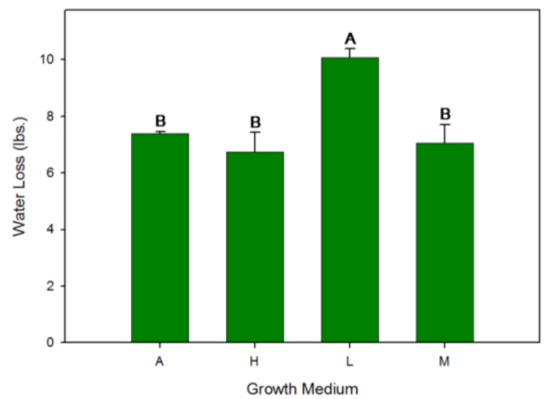

Figure 7b. Total water loss from Green Paks™ without plants and drainage layer oriented with cups down between 9/18/06-9/21/06. Bars with different letters are significantly different ($\alpha<0.05$). Error bars represent plus one standard error. n=3 for all

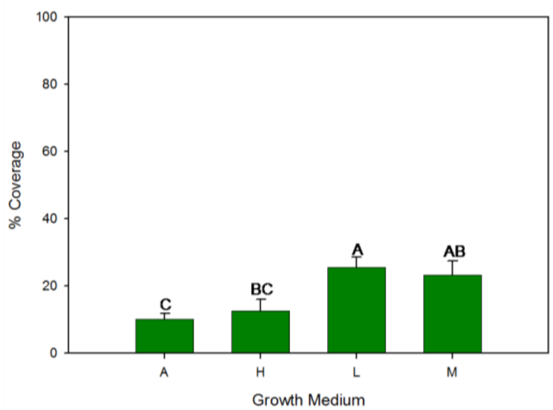

Figure 7c. Percent coverage of *S. kamtschaticum* plants in Green Paks™ with drainage layer oriented with cups down on 10/05/06. Bars with different letters are significantly different ($\alpha<0.05$). Error bars represent plus one standard error. n=12 for all.

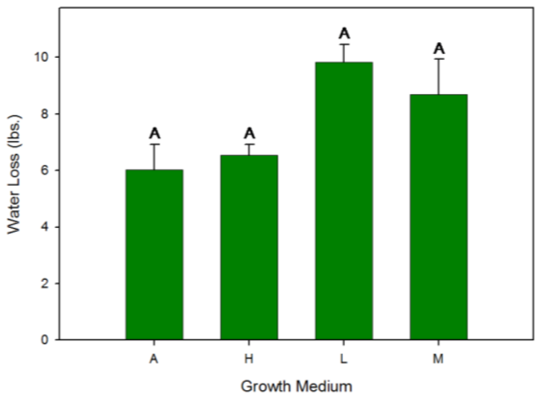

Figure 8a. Total water loss from Green Paks™ with plants and drainage layer oriented with cups down between 7/15/08-7/18/08. Bars with different letters are significantly different ($\alpha<0.05$). Error bars represent plus one standard error. n=3 for all

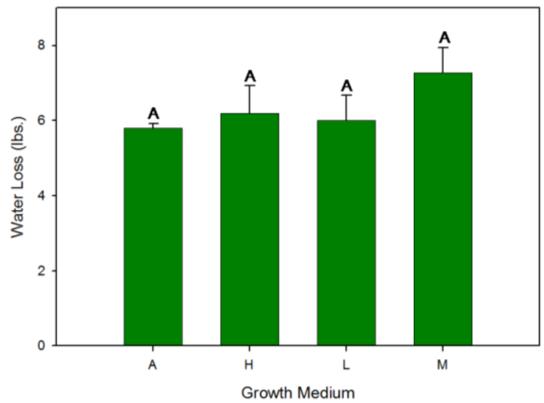

Figure 8b. Total water loss from Green Paks™ without plants and drainage layer oriented with cups down between 7/15/08-7/18/08. Bars with different letters are significantly different ($\alpha<0.05$). Error bars represent plus one standard error. n=3 for all

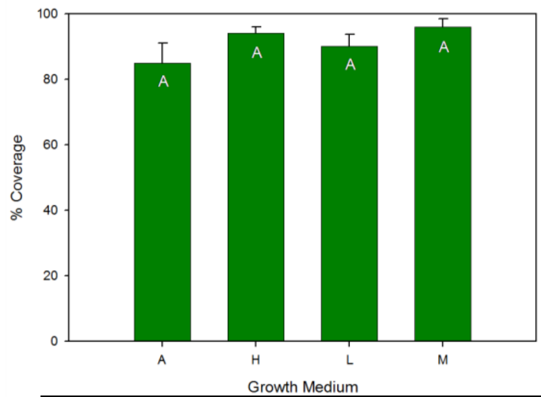

Figure 8c. Percent coverage of mixed *Sedum* spp. in Green Paks™ with drainage layer oriented with cups down on 11/20/08. Bars with different letters are significantly different ($\alpha<0.05$). Error bars represent plus one standard error. n=12 for all.

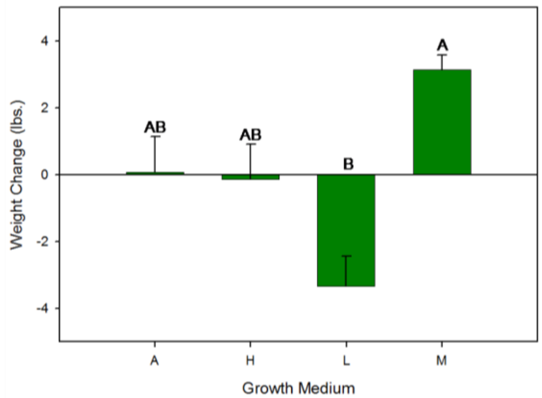

Figure 9a. Weight change in Green Roof Blocks™ with plants over two years (2006-2008). Bars with different letters are significantly different (α<0.05). Error bars represent plus one standard error. n=3 for all.

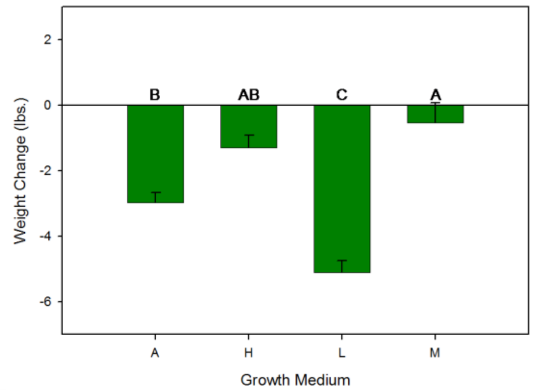

Figure 9b. Weight change in Green Roof Blocks™ without plants over two years (2006-2008). Bars with different letters are significantly different (α<0.05). Error bars represent plus one standard error. n=3 for all.

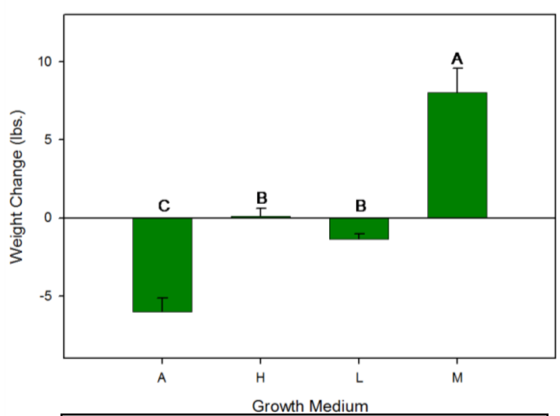

Figure 9c. Weight change in Green Paks™ with plants over two years (2006-2008). Bars with different letters are significantly different (α<0.05). Error bars represent plus one standard error. n=6 for all.

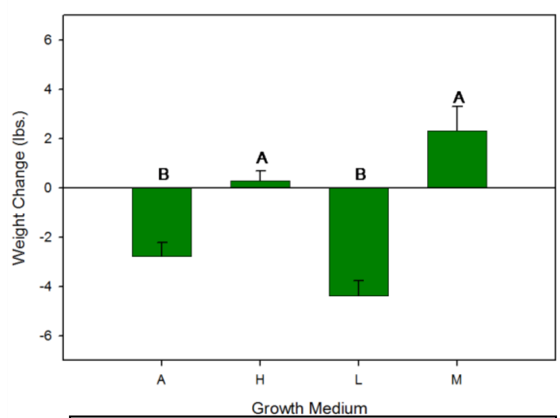

Figure 9d. Weight change in Green Paks™ without plants over two years (2006-2008). Bars with different letters are significantly different (α<0.05). Error bars represent plus one standard error. n=6 for all.