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EVALUATION OF PERENNIAL PLANT SUCCESS ON A GREEN ROOF

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by

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A Thesis
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Approved by

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TITLE: EVALUATION OF PERENNIAL PLANT SUCCESS ON A GREEN ROOF

MAJOR PROFESSORS: Karen Stoelzle Midden, S. Alan Walters

A two-year study (2011-2012) was conducted on a section of an extensive green roof of the Agriculture Building at Southern Illinois University to evaluate the adaptability of four plant species to green roof culture.

Extensive green roof survival, growth, and general success of four plant species (*Allium schoenoprasum* L., *Dianthus gratianopolitanus* 'Grandiflorus' Vill., *Sedum kamtschaticum* Fisch. & C.A. Mey. Sp. ellacombianum (Praeger) R.T. Clausen, and *Talinum calycinum* Engelm.) were compared using two propagating mediums (a peat-based greenhouse medium and a lightweight aggregate medium) integrated with three amendments to enhance plant growth, which provided four medium treatments (lightweight aggregate with vermicompost, lightweight aggregate with mycorrhiza, peat-based greenhouse medium, and SIUC green roof mix).

The greenhouse medium resulted in higher plant growth ratings than the lightweight aggregate medium. *Dianthus* had the most success, with the highest plant height plus width (40.3 cm) and plant rating scores (2.9/5.0). The amendment that showed the most potential was the mycorrhizal treatment, providing higher plant height plus width scores than the control (SIUC green roof mix).

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TABLE OF CONTENTS

LIST OF TABLES

TABLE PAGE

CHAPTER 1

LITERATURE REVIEW

Green Roof Types. The term "green roof" refers to a system of roofing technology that employs plant life for roof covering instead of traditional covering materials such as shingles (Getter and Rowe, 2008). Green roofs differ from roof gardens in that green roofs have a layered system with vegetation and a growing medium, planted over a waterproofing membrane. Green roofs have a much lighter planting medium than roof gardens and offer environmental and other benefits, including storm water management and building insulation. Green roofs have been in existence for centuries, some dating back to 500 BC (Getter and Rowe 2006) and are increasingly replacing traditional roofing given their many environmental and economic advantages. Green roofs have the ability to minimize storm water runoff, improve water quality, increase the roof membrane longevity, provide insulation that can lower energy costs, reduce the urban heat island effect, reduce air pollution, offer acoustical benefits, increase food security of fresh locally grown food, encourage biodiversity in urban areas, and improve aesthetics (Peck, 2008; Snodgrass and McIntyre, 2010).

North America's green roof research and development is just emerging as compared to Germany. Germany is the world leader of green roof development. The Forschungsgesellschaft Landschaftsbau Landschaftsentwicklung or the FLL (The Landscaping and Landscape Development and Research Society) is an organization in Germany that established a standard method of green roof installation and general labor guidelines (Kirby, 2007). With these green roof regulations, incentives and organizations, Germany has been able to construct one billion square feet of green roof space (Phillippi, 2002). In 2004, a survey of the 488 German municipalities with populations over 10,000 was completed by the FBB, (Fachvereinigung

Bauwerksbegrünung e.V) the main green roof association in Germany. Of the 398 (27%) respondents, the results showed that 70 (18%) offer direct financial incentives, 201 (51%) offer storm water fee credits, and 145 (36%) incorporate green roof requirements into development (Ngan, 2009). Additionally, some German municipalities require a green roof on new flat roof construction while other municipalities offer tax deductions to homeowners with green roofs and tax additions to homeowners with impervious roof surfaces.

While professionals in North America have adopted several German green roof practices, adaptations are being developed to fit the climate and regulations of North America. The organization, Green Roofs for Healthy Cities has taken the lead in developing Green Roof Guidelines appropriate for North America. The city of Chicago, Illinois has led the green roof movement for several years with 509 vegetated roofs covering a total of 5,564,412 ft^2. There is currently more than 3 million square feet of green roof in Washington, D.C. and Seattle. With other major cities attempting to gain public and political support to include green roofs in city budgets, the functions of the roofs have also been growing beyond storm water management and energy savings to include improving biodiversity of insects and animals, providing produce (Ouellette et. al.) and creating outdoor spaces for society to enjoy in urban environments (Marinelli, 2006). The contemporary green roof must be structurally and culturally capable of supporting these additional interests and trends.

Green Roofs and Biodiversity. Green roof research and development has traditionally been concerned with building performance. Most research has focused on energy consumption and storm water retention (Marinelli, 2006) and utilized *Sedum* species as the vegetation of choice. Contemporary green roofs have evolved from the traditional *Sedum* green roof installation to include different medium layers and varied plant species. This change is due to an increased interest in aesthetic value, food production and plant species biodiversity expanding the benefits and opportunities that a green roof may provide (Marinelli, 2006). The traditional *Sedum* mat, commonly used in extensive green roofs, is unsatisfactory to provide or replace habitats for ground dwelling insects that are not highly mobile (Brenneisen, 2006). The traditional *Sedum* green roof also provides low plant biodiversity. A green roof with many plant species will provide a prolonged blooming period which will attract diverse forms of wildlife and add to the overall aesthetic value.

The desire to improve the biodiversity of green roofs in urban areas challenged with lack of space for diverse and/or natural habitats has created a niche role for green roof design to improve the conservation of biodiversity. Research findings have been encouraging and suggest that if appropriate environments are created, plants and animals will migrate to these green habitats and establish themselves (Marinelli, 2006). Furthermore, Köhler (2006) investigated green roofs designed to increase biodiversity of plants and determined that a relatively diverse flora is possible on green roofs if varied sunny and shady microclimates are created, initial plantings are enhanced, and a minimal amount of irrigation/maintenance is provided.

In Switzerland, green roofs are becoming an important part of the country's biodiversity strategy. Research conducted at a 90-year-old green roof in Zurich, which became an orchid meadow with a high conservation value, had design criteria that stipulated the use of natural soil as well as different substrate thicknesses throughout the roof. These stipulations were used to re-create a habitat that would be suitable for local plant species. It was also noted that several bird species used the green roof as a breeding habitat. The data also showed that birds would, in some cases, permanently change their breeding sites depending upon the needs of their young. A similar green roof was created on top of the Rhypark building in Basel, Switzerland that provided a dense combination of microhabitats supporting 79 beetles and 40 spider species; with 13 of the beetles and seven of the spiders being endangered species (Brenneisen, 2006). Furthermore, Kadas (2006) examined invertebrate diversity on green roofs in London, focusing on three groups: spiders, beetles, and aculeate Hymenoptera (wasps, bees, and ants); a higher abundance of invertebrates was identified on green roofs compared to traditional roofs, and at least 10% of the species studied were rare. Green roofs have also been evaluated for potential habitat for other species such as birds. Baumann (2006) indicated that green roofs can provide not only a food habitat, but also a breeding habitat for ground-nesting birds such as the endangered little ringed plover (*Charadrius dubis Scopoli.*) and northern lapwing (*Vanellus vanellus L.*).

A successful North American green roof that displays high plant biodiversity is Chicago's City Hall. This green roof was completed in 2001. One of its purposes was to test a variety of green roof systems and medium depths. The roof area is 38,800 ft^2, and green roof portion encompasses 20,300 ft^2 and has over 150 varieties of plants (Yocca, 2012). The medium depth varies from 4 to18 in. These different media depths allow a wide variety of plant types to grow and develop. While the areas with only 4 in. depths allow only groundcovers and plants with shallow roots to grow successfully, the areas with depths of 18 in. allow for shrubs, small trees, and plants with deeper roots to grow effectively. The Chicago City Hall green roof supports several beehives and includes native plants that attract wildlife to help increase biodiversity.

Increasing plant diversity, food production and wildlife habitats on green roofs is a complex issue. The majority of annual and perennial plants associated with traditional gardens cannot be used (Snodgrass and Snodgrass, 2006) due to the harsher environmental conditions provided on a roof. Successful green roof plants tend to be those that self-seed themselves, spread quickly, and are drought/heat tolerant, structurally sound, and disease/pest resistant (Getter and Rowe, 2008). In the typical green roof, plants must be able to survive with little maintenance and tolerate the fabricated environment.

Green roof media, probably the most important component of a green roof, is one of the areas of green roof design that has not been fully investigated (Young et al., 2014). The challenge is to provide nutrients and moisture holding capacity without adding additional weight. The weight limit dictates the permissible medium depth. Most green roof media research has focused on the effects that depth has on plant growth and survival (Rowe et al., 2012; Thuring and Berghage, 2010). While plant success does improve with medium depth there are several other considerations, including cost and roof strength. An alternative to increasing the depth of a green roof medium for healthy plant establishment may be using an alternative propagation medium during the germination of plants in the greenhouse, which will allow plants to acclimate to green roof media during greenhouse germination and establishment. Despite the potential benefits of germinating seeds in green roof media, little research has been conducted to address this issue.   Young et al. (2014) found that media containing small brick green roof medium (20% brick at 2–5 mm particle diameter), and green water compost outperformed a large brick green roof medium (20% large brick of 4–15 mm diameter). However, subsequent plant performance on a green roof was not evaluated.

Green roof plants are typically established by one of six different methods: seeds, cuttings, plugs, nursery containers, vegetated mats, and module trays (Snodgrass and Snodgrass 2006). Nursery containers, vegetative mats, and modules are grown as individualized containers and then placed on a green roof; whereas seeds, cuttings, and plugs can be directly integrated into the green roof medium. While seedings offer the advantage of low cost installation, plugs have an existing root system and are better suited to the course green roof aggregate than seeds. Plugs also allow growers to visualize what the surface design will look like once planted (Getter and Rowe 2006). However, Getter and Rowe (2007) found plugs planted in the fall that do not become fully established can lift out of the medium due to freezing and thawing action, exposing the roots. The cold exposure can damage or result in plant death.

Questions remain unanswered regarding seed germination and establishment in a green roof medium, and if this results in improved plant establishment on a green roof. Therefore, an experiment was designed to compare green roof survival, growth, and general success of four plant species using two propagating media (a peat-based greenhouse medium and a lightweight aggregate medium) integrated with four medium treatments (lightweight aggregate with vermicompost, lightweight aggregate with mycorrhizae, peat-based greenhouse medium, and SIUC green roof mix). The objectives of this study were to: 1) Compare the success of four perennial plants on an extensive green roof that were propagated in different base media, and 2) Compare how the amended treatments applied to the base media affect the success of four perennial plants on an extensive green roof.

CHAPTER 2

PLANT GROWTH WITH DIFFERENT MEDIA ON A GREEN ROOF

ABSTRACT

Extensive green roofs continue to be popular in North America and continued research on green roof systems and performance is necessary to improve the way in which green roofs function. Green roof performance and benefits have traditionally been measured by their ability to capture storm water, cool the building below by means of shading and evaporative cooling, and their ability to successfully support plant life. Extensive green roofs have harsh growing conditions and establishment in these conditions can be difficult. The design of extensive green roofs continue to be dominated by shallow, light weight substrates and extremely drought tolerant plants.

While research shows that establishing a solid root system on an extensive green roof is vital for plant survivability, little research has been conducted on the plug medium itself. In response to this issue, this research examines an alternative approach to green roof plant propagation. A two-year study (2011-2012) was conducted on the extensive green roof atop the Agriculture Building at Southern Illinois University.

The survival, growth and overall general success of four plant (Allium schoenoprasum L., Dianthus gratianopolitanus 'Grandiflorus' Vill., Sedum kamtschaticum Fisch. & C.A. Mey. Sp. ellacombianum (Praeger) R.T. Clausen, and Talinum calycinum Engelm.) were compared using two propagating media (a peat-based greenhouse medium and a lightweight aggregate medium) integrated with four medium treatments (lightweight aggregate with vermicompost, lightweight aggregate with mycorrhizae, peat-based greenhouse medium, and SIUC green roof mix

The greenhouse medium resulted in significantly higher plant growth ratings than the lightweight aggregate medium. Dianthus had the most success, with the highest plant height plus width (40.3 cm) and plant growth rating scores (2.9/5.0). The treatment that showed the most potential was the mycorrhizae treatment, with significantly higher plant height plus width scores than the control (greenhouse medium).

INTRODUCTION

The world has experienced unprecedented urban growth in recent decades. In 2008, for the first time, the world's population was evenly split between urban and rural areas. There were more than 400 cities having a population over 1 million and 19 over 10 million. More developed nations were about 74 % urban, while 44 % of residents of less developed countries lived in urban areas. However, urbanization is occurring rapidly in many less developed countries. It is expected that 70 % of the world population will be urban by 2050, and that most urban growth will occur in less developed countries. Consequently, green spaces are decreasing in size or disappearing given this continued growth of cities and developed areas. In 2012, according to the U.S. Natural Resources Conservation Service, 35.2 million acres of land has been developed in the United States over the last two decades, a land area roughly equivalent to the state of New York (34.9 million acres). Moreover, between the years 2001 and 2003, 2.9 million of those acres were developed (Moffett & Hasse, 2006). Without replacement of green areas, this type of expansion is not only facilitating a negative impact on the urban biodiversity but is creating a "human disconnect with nature" (Miller, 2005).

Green roofs offer an alternative to the traditional rooftop by replacing hard surfaces with vegetation, wildlife, and natural beauty otherwise reduced or eliminated. They offer a unique solution for urban growth by restoring green spaces and natural habitats, yet unlike parks and other ground level green spaces, they do not infringe on the continuing spread of urban structures. In fact, green roofs are dependent upon urban structures. The challenge is to create an environment suitable to grow plants on a roof which is often a complex issue.

A standard green roof medium is composed of a lightweight aggregate with limited amounts of added amendments. To maintain the weight limits of a roof structure, the growing medium depth and the percentage of organic matter must be managed to not exceed these limits. For example, a weight limit ranging from 10 to 25 lb./ ft^2 (50 – 120 kg / m^2) on an extensive green roof medium averages only a three-inch depth.

Due to the abnormal environment for plant growth and challenges for roof survival, it is critical to begin with a healthy plant in this system. Planting from plugs (seedlings grown in individual cells) is one common installation method. Plugs have an existing root system that gives them an advantage over using seeds and cuttings, the two other methods most often used for green roof plantings. However, plugs often have problems with their roots establishing in the green roof medium. Plugs are typically grown in a peat-based medium that is high in organic matter and nutrients (Getter and Rowe 2007). Furthermore, plants grown in multi-cell containers need to have their roots cut to avoid roots growing in a circle around the interior of the cell, as they will often maintain that shape and growing pattern after planting. Given the typical low organic matter, nutrients, and water supply on green roofs, it is important to find methods to establish plugs quickly in a green roof medium for them to survive (Koehler 2010). Getter and Rowe (2007) found that *Sedum* plugs planted in spring had an 81 % survival rate compared to a 23% survival rate in an autumn planting. The spring plugs had 16 weeks to establish, while the autumn plugs had less than five weeks to establish before the onset of winter weather. Colder temperatures can cause frost heaving which is an upward swelling of the soil caused by the presence of ice. Plugs that have not been adequately established can be pushed out of the soil and have their roots damaged. This emphasizes the advantage of having roots established into the green roof medium before harsh winter weather. Therefore, a study was designed to compare green roof survival, growth, and general success of four plant species using two propagating media (a peat-based greenhouse medium and a lightweight aggregate medium) integrated with four medium treatments (lightweight aggregate with vermicompost, lightweight aggregate with mycorrhizae, peat-based greenhouse medium, and SIUC green roof mix) on the Agriculture Building green roof at Southern Illinois University in Carbondale.

METHODS AND MATERIALS

A study was conducted in 2011 and 2012 on a section of the 3,700 ft² green roof of the Agriculture Building at Southern Illinois University in Carbondale, Illinois (SIUC). The SIUC green roof was installed in the fall of 2010 and is used for student research and educational purposes. The study was to evaluate plant success based on the media components used in their plug production, as well as the species as a green roof plant. The components of the green roof (from bottom up) include a waterproof membrane layer (thermoplastic polyolefin), a soft fabric protection layer, a root barrier, an “egg crate” style drainage layer, a filter fabric, 3 ‘of green roof mix (lightweight aggregate + organic matter), and plant material. The weight limitation for the system is 23 lb./ ft² (Midden, 2012).

Plant Selection. The four-plant species chosen for this study are potential staple green roof plants based on their physiological characteristics and opportunity to increase biodiversity in an ‘unnatural’ environment. The four selected plants were: Allium schoenoprasum L., Dianthus gratianopolitanus ‘Grandiflorus’ Vill., Sedum kamtschaticum Fisch. & C.A. Mey. Spp. ellacombianum (Praeger) R.T. Clausen and Talinum calycinum Engelm.

Allium is a drought tolerant flowering plant that attracts wildlife such as bees and butterflies. This plant has the survival and growth characteristics of an invasive plant species and has been shown to adapt on the roof after a few years (Dunnett et al, 2011). Dianthus is exceptionally hardy and has a long flowering period from spring to late summer with flowers that attract a multitude of wildlife (Olszewski & Young, 2011). Sedum is a commonly used green roof plant and is the “fail safe” plant. Sedum kamtschaticum is a taller and more attractive Sedum that is also noted as being drought tolerant (Dunnett et al, 2011). Lastly, Talinum is a native perennial which often grows and thrives in rocky, rough terrain making it ideal for a green roof environment. This low maintenance plant is excellent at self-sowing and will rapidly colonize a given area. The flowers are pink to red with about five to eight petals and attracts bees and butterflies. The stems grow to approximately 8 in. height with succulent leaves. The flowers will open only during peak pollination periods, around noon to mid-afternoon in most areas, during the day to conserve energy (Missouri Botanical Garden, 2012).

Propagation Mediums of Plugs. The two-propagating mediums utilized in this study were a greenhouse medium and lightweight aggregate. The greenhouse medium was a standard mix processed in the SIUC Teaching Greenhouse. It has a high organic and nutrient content and is similar to what other greenhouses and commercial nurseries use to sow and germinate seeds. The lightweight aggregate, purchased from Midwest Trading Company in Maple Park, Illinois, is expanded baked clay used for the volume of space it takes up with minimal added weight. The porosity of the lightweight aggregate is also beneficial for water drainage and aeration.

The four media treatments evaluated were: lightweight aggregate with vermicompost, lightweight aggregate with mycorrhizal fungi, the SIUC green roof mix, and greenhouse medium (control). The greenhouse medium (control) had nothing added to the propagating medium.

Vermicompost, composed of coffee grounds and dining hall food waste, was obtained from the SIUC University Farms Vermicompost Center. This vermicompost was high in nitrogen and provided a nutrient rich growth medium. Mycorrhizae are fungi that have a symbiotic relationship with plant roots. The plant roots provide the fungus with carbohydrates while the fungus enhances the uptake of nutrients by the plant (Brundrett, 1991). The green roof mix was also purchased from Midwest Ground Cover and mixed specifically for the SIUC extensive green roof.

The SIUC green roof mix provides an organic component in conjunction with lightweight aggregate (Curry, 2012). The mycorrhizae utilized in this study were obtained from Bio Green (Volvo, Illinois). The vermicompost and green roof medium were mixed separately at a 1:1 ratio with the lightweight aggregate and the greenhouse media. The mycorrhizal were mixed with the associated base medium (equivalent to 10 lb./ yd^3).

Research Design. On May 13, 2011 and 2012, the plugs were planted at a 3-inch depth in a 96 ft^2 area on the northwest side of the SIUC green roof. The perennial plugs were planted 12" on center in the 12' by 8' plot in a 2 (propagating mediums) x 4 (medium treatments) x 4 (plant species) Factorial Design with 3 replications. The design was chosen to account for the different growth habits and spread of the plant species evaluated. The green roof medium consisted of 20% vermicompost and 80% lightweight aggregate. A 12-inch unplanted barrier bordered the plot to prevent outside competition from interfering with the experiment. The plant species were planted in a mixed plot according to treatments. The plants were watered by hand as needed, which was almost daily during the summer and approximately every three days in the fall and spring, and almost no irrigation during the winter.

Data Collection. Beginning June 2011 and ending in early January 2012 the plants were measured by height and width every other month. Plants were required to be alive to be included in the measurement. In addition, an observational rating scale was utilized and was based on plant health, plant growth, and if the desired characteristics of the given plant species were achieved. This rating scale quantifies plants from 0-5, (0= the plant is dead, 1= the plant is showing signs of stress and has declined in growth and/or desired characteristics, 2= the plant has changed none/very little from last data collection, 3= plant is showing a little improvement in growth and/or desired characteristics, 4= plant is showing much improvement in growth and desired characteristics, and 5= plant is showing optimal spread and demonstrating all desired characteristics (Monterusso et. al., 2005). Recording of the data resumed in April 2012 and terminated on May 13, 2012 completing a one-year cycle. At the end of the first year, viable plants that remained alive were enumerated to determine plant species percent survival. On May 21, 2012 the planting was replicated adjacent to the first planting on the southwest side of the SIUC green roof, directly across from the first planting. The recording/research procedure was identical for the second year.

Statistical Analysis. Data was analyzed using analysis of variance (ANOVA) and mean separation was performed by the Student's t Multiple Range test with $P < 0.05$. Data analysis was done using JMP Statistical Discovery Software (JMP, 2012). Plants that were not alive at the initiation of this experiment were not used and seen as outliers for plant height plus width and vigor. For the plant rating scale, these plants were recorded as a 0. Data collected from year one and year two did not interact ($P > 0.05$) with any of the main effects, allowing the data from both years to be combined for statistical analysis**.** Since there were no interactions detected ($P > 0.05$) among all factors, only the main effects are presented.

RESULTS

Base Medium, Treatment and Plant Species Influences on Plant Characteristics.

The greenhouse medium did not differ (P> 0.05) from the lightweight aggregate for plant growth characteristics. No interactions (P> 0.05) were detected between the base media and plant species (Allium, Dianthus, Talinum, and Sedum) or treatments evaluated (greenhouse medium, green roof mix, mycorrhizae, or vermicompost). Therefore, only main effects are presented (Table 1, 2 and 3).

Table 1. The influence of base medium on overall growth of four plant species pooled over the 2011 and 2012 growing season on the SIUC green roof.

Medium	Plant Growth
Greenhouse	27.1 A
Lightweight Aggregate	25.1 A

Means with similar letters are not significantly different at P < 0.05.
The four-plant species evaluated were: Allium, Dianthus, Sedum and Talinum.

Although the base medium had no influence on overall growth spread of the four-species evaluated (Table 1), the specific treatment applied to the base medium did have an effect on resulting plant growth (Table 2). The mycorrhiza treatment provided significantly (P < 0.05) greater plant height plus width scores than the control treatment. The vermicompost treatment and green roof mix treatments resulted in height plus width scores similar to the mycorrhiza treatment scores but were not statistically different from the control (greenhouse medium). No interactions (P> 0.05) were detected between treatments evaluated and plant species (Allium, Dianthus, Talinum, and Sedum) nor base media (greenhouse medium and lightweight aggregate).

Table 2. The influence of base medium treatment on overall growth of four plant species pooled over the 2011 and 2012 growing season on the SIUC green roof.

Treatment	Plant Growth
Lightweight Aggregate + Mycorrhizae	29.8 A
Green Roof Mix	26.7 AB
Lightweight Aggregate + Vermicompost	26.4 AB
Control (Greenhouse Medium)	24.5 B

Means with similar letters are not significantly different at P < 0.05.
The four plant species evaluated were: Allium, Dianthus, Sedum and Talinum.

This study found differences in the spread of the four-different species of green roof plants (Table 3). Dianthus had greater amount of spread (P<0.05 than the other three plant species Allium, Sedum and Talinum. Allium had greater (P<0.05) height plus width values than Sedum and Talinum; while Sedum had greater (P<0.05) height plus width values than Talinum

Table 3. The influence of plant species on overall growth of four plant species pooled over the 2011 and 2012 growing season on the SIUC green roof.

Plant Species	Plant Growth
Dianthus	40.3 A
Allium	30.4 B
Sedum	15.2 C
Talinum	10.7 D

Means with similar letters are not significantly different at P < 0.05.
The four plant species evaluated were: Allium, Dianthus, Sedum and Talinum.

Base Medium, Treatment and Plant Species Influences on Plant Survival Rates.

No interactions (P> 0.05) were detected between base medium evaluated and treatments (greenhouse medium, green roof mix, mycorrhizae, and vermicompost) or plant species (Allium, Dianthus, Talinum, and Sedum), therefore only main effects are presented (Tables 4, 5 and 6).

Table 4. The influence of base medium on the survival rates of four plant species pooled over the 2011 and 2012 growing season on the SIUC green roof.

Medium	Plant Survival Rates (%)
Greenhouse	74.3 A
Lightweight Aggregate	55.1 B

Means with similar letters are not significantly different at P < 0.05.
The four plant species evaluated were: Allium, Dianthus, Sedum and Talinum.

The greenhouse medium had a significantly higher (P < 0.05) plant survival rate than the lightweight aggregate medium. The base medium had a definite influence on the survival rates of the four plant species evaluated on the SIUC green roof. The greenhouse medium resulted in nearly a 19% increase in plant survival rates on the SIUC green roof environment. However, the addition of various treatments to the base medium did not (P> 0.05) increase survival rates (Table 5).

Table. 5 The influence of base medium treatment on the survival rates of four plant species pooled over the 2011 and 2012 growing season on the SIUC green roof.

Treatment	Plant Survival Rates (%)
Lightweight Aggregate + Mycorrhizae	62.5 A
Green Roof Mix	72.7 A
Lightweight Aggregate + Vermicompost	66.6 A
Control (Greenhouse Medium)	60.0 A

Means with similar letters are not significantly different at P < 0.05.

The four plant species evaluated were: Allium, Dianthus, Sedum and Talinum.

The four-plant species differed in their survival rates on the SIUC green roof (Table 6). Dianthus had higher survival rates ($P < 0.05$) than the other three plant species evaluated: Sedum, Talinum and Allium. Sedum and Talinum had higher ($P < 0.0$)5 plant survival rates than Allium

Table 6. The influence of plant species on the survival rates of four plant species pooled over the 2011 and 2012 growing season on the SIUC green roof.

Plant Species	Plant Survival Rates (%)
Dianthus	84.2 A
Sedum	66.6 B
Talinum	66.6 C
Allium	47.3 D

Means with similar letters are not significantly different at $P < 0.05$.
The four plant species evaluated were: Allium, Dianthus, Sedum and Talinum.

Base Medium, Treatment and Plant Species Influences on Plant Rating.

No interactions ($P > 0.05$) were detected between the base media evaluated and treatments (greenhouse medium, green roof mix, mycorrhizae, or vermicompost) or plant species (Allium, Dianthus, Talinum, and Sedum) (Tables 7, 8 and 9).

The comprehensive observational vigor rating indicated differences between base mediums. The greenhouse medium had a significantly ($P < 0.05$) higher plant rating than the lightweight aggregate.

Table 7. The influence of base medium on plant growth ratings of four plant species pooled over the 2011 and 2012 growing season on the SIUC green roof.

Medium	Plant Growth Rating
Greenhouse	2.7 A
Lightweight Aggregate	1.7 B

Means with similar letters are not significantly different at $P < 0.05$.
The four plant species evaluated were: Allium, Dianthus, Sedum and Talinum.

The addition of various treatments to the base medium did not ($P > 0.05$) increase plant ratings (Table 8). However, differences were observed between plant species for the comprehensive growth spread rating (Table 9). Dianthus had higher ($P < 0.05$) growth than Allium and Talinum. Sedum was also had higher ($P < 0.05$) than Talinum.

Table. 8 The influence of base medium treatment on plant growth ratings of four plant species pooled over the 2011 and 2012 growing season on the SIUC green roof.

Treatment	Plant Growth Rating
Control (Greenhouse Medium)	2.5 A
Lightweight Aggregate + Vermicompost	2.3 A
Green Roof Mix	2.1 A
Lightweight Aggregate + Mycorrhizae	1.9 A

Means with similar letters are not significantly different at $P < 0.05$.

The four plant species evaluated were: Allium, Dianthus, Sedum and Talinum.

Table 9. The influence of plant species on plant growth spread of four plant species pooled over the 2011 and 2012 growing season on the SIUC green roof.

Plant Species	Plant Growth Rating
Dianthus	40.3 A
Allium	30.4 B
Sedum	15.2 C
Talinum	10.7 D

Means with similar letters are not significantly different at $P < 0.05$.
The four plant species evaluated were: Allium, Dianthus, Sedum and Talinum.

DISCUSSION

1. Plant Growth Spread.

Comparisons of propagating base media (greenhouse versus lightweight aggregate) did not result in growth differences for any of the four-plant species or for any of the four treatments evaluated (Table 2). This finding is surprising in that the greenhouse medium has a higher organic matter and nutrient content than the aggregate which is baked clay and a low nutrient composition. The porosity of the lightweight aggregate also has lower water holding capacity than the greenhouse medium (Ball, 1998; Brady and Weil, 2008; Styer, 2000; Styer and Koranski, 1997). However, the lightweight aggregate may have provided some important benefits, due to its porous nature which ensures an adequate supply of air to enable plants to be established quickly and develop healthy root systems (Brady and Weil, 2008;). The lack of any significant differences between these two-base media suggests that plants destined to grow on green roofs may be initially started in a wider range of propagating material than commonly thought when the desired outcome is plant spread. Aggregates can be more economical and much lighter than the traditional greenhouse medium.

Although sedum may be the most frequently used plant on green roofs due to its drought tolerance and shallow root system, Dianthus provided greater overall growth than Sedum, Allium or Talinum. This may be due to the morphological growth pattern and physical structure of Dianthus which grows equally 20 to 25 cm in height and width, whereas, the other plant species evaluated grow primarily in either height or width (Mineo, 1999). The green roof also provided an environment with open areas for expansion, a growing condition that Dianthus prefers. This plant has high aesthetic appeal as it blooms in the late spring or early summer with large pink flowers (Still, 2004). Like all herbaceous plants, Dianthus dies back each year which provides a benefit for green roofs. Yespen (2009) stated that plants on a green roof should produce their own compost, with dead leaves and a natural turnover of organic material that creates an equilibrium. While taller plants are not usually considered most adaptable to green roof culture, this study indicates that if planted correctly, Dianthus can be a viable, important and aesthetic species on a green roof (Snodgrass and Snodgrass, 2006).

The addition of one amendment (mycorrhizae) to the light weight aggregate did increase plant growth compared to the control (greenhouse medium. The mycorrhizal provided a plant growth increase of nearly 22% compared to the control (Table 2). This result may be due to mycorrhizae's ability to enhance the efficiency of plants to absorb water and may also aid in drought resistance and stress tolerance. The expanded root system provided by mycorrhizae also allows plants much greater access to nutrients and stability than they could provide to themselves, especially under difficult environmental conditions that often occur on a green roof. (Busenbark, 2018). The vermicompost and green roof mix treatments resulted in plant growth similar to the mycorrhizae although they did not differ ($P > 0.05$) from the greenhouse medium. This would suggest that while the nutrient value of the vermicompost and organic properties of the green roof mix may provide benefits that result in larger plant growth, they are not significant enough to differentiate from the greenhouse medium.

2. Survival Rate

Propagating seeds in a lightweight aggregate medium for use on green roofs resulted in lower green roof survivability rates than propagating seeds in the traditional greenhouse media. The greenhouse medium had a significantly higher plant survival rate at nearly 74% than the lightweight aggregate medium (Table 4).   Since the greenhouse medium has added nutrients and provides better root support compared to the mineral, non-organic lightweight aggregate, it appears that the greenhouse plugs better survive the transition and become more successfully established to the green roof environment when plants are grown in this type of medium.

Dianthus, which had the highest growth rates also had higher survivability than the other three plant species evaluated, although Sedum and Talinum had higher survival rates than Allium. The higher survival rate for Dianthus may be related to its higher plant spread in this study. Its greater overall growth may have resulted in a larger root system. This root system may have resulted in improved water and nutrients absorption. The high survival rate may also reflect the species' ability to grow in rocky terrain which presents many similar growing difficulties as the green roof environment (Allwood, 1954). Dianthus has advantages in green roof survivability as it is hardy to 40°F and experiences low fungal problems due to the open, low humidity green roof environment (Still 2004). Hawke (2015) also reported higher spread and survival rates for Dianthus compared to more traditional green roof plants such as *Sedum*.

3. Plant Rating

The greenhouse medium had higher plant vitality rating score than lightweight aggregate (Table 7). The control (greenhouse medium) performed better than the lightweight aggregate on two of the three dependent measures: plant survival and plant vitality. Plant growth spread is the only dependent variable in this study where the greenhouse medium did not improve relative to the lightweight aggregate. Futhermore, the organic matter and higher water holding capacity associated with the greenhouse medium appears to have influenced plant survival rate and characteristics such as blooming, foliage and plant fullness. An explanation for the lack of differences detected between the greenhouse medium and the lightweight aggregate for height plus width may be due to plant adaptations to stress associated with green roofs. Limitations in plant growth (e.g. overall reductions in plant size) may be a desirable outcome on green roofs in that it reduces the amount of stress that a plant must overcome to survive (Nagase and Dunnett, 2011).

The medium treatments had no effect on the plant rating scale (Table 8), although plant species influenced plant rating (Table 9). Dianthus had higher rating scores than Allium and Talinum. Dianthus outperformed the other plant species evaluated possibly due to its cold tolerance, low humidity requirements and the well-drained soil provided in the green roof environment (Allwood, 1954). Dianthus also has dense, compact foliage that could protect the stalk and flowers from wind damage. Moreover, its greater spread may have resulted in improved root establishment and water and nutrient absorption.   Sedum had greater plant growth than Talinum. The low growth of talinum may have resulted from the flower (which is a desired characteristic criteria) having a 20-25 cm thin stalk, which allowed it to be damaged or removed by the wind on the mainly unprotected SIUC green roof.

Root establishment of these four plants species in a green roof environment depended upon the seed propagation medium. The greenhouse medium had a significantly higher survival rate and plant growth rating scores than the lightweight aggregate, even when the light weight aggregate was integrated with mycorrhizae, vermicompost, or a green roof mix. However, this study indicated that green roof plants seeded in a lightweight aggregate will reach a size similar to plants seeded in traditional greenhouse medium. This may provide an advantage for growers under certain circumstances. Survivor rate and plant rating results may have changed if plants were started in another medium before being transplanted to the green roof.

In this study, Dianthus provided overall growth and survival rates than the other three plant species (Sedum, Talinum, and Allium). Researchers have suggested that increased spread may be detrimental on extensive green roofs because the environmental conditions often will not support wider taller plants (Moffett and Hasse, 2006; Monterusso et al, 2005; Nagase and Dunnett 2011). That was not the case in this study as *Dianthus* had higher spread and survival rate than the other plants. This finding indicates that *Dianthus* can be a viable and aesthetic species on a green roof. It should also encourage continued efforts to study a broad selection of native plants with superior ornamental qualities on green roofs.

In this study the mycorrhizal treatment increased height plus width scores for all plant species, suggesting that mycorrhizae's ability to expand root systems may also enhance the efficiency of plants to absorb water and may also aid in drought resistance and stress tolerance. Busenbark (2018) has proposed that the expanded root system provided by mycorrhiza allows plants much greater access to nutrients and stability than they could get by themselves, especially under difficult conditions faced on a green roof

CONCLUSION AND FUTURE RECOMENDATIONS

Green roof plant success as well as plant diversity must continue to be examined and studied. The design of greenhouse propagating media has not been studied as much as the design of green roof media. This small exploratory study documenting the impact of two different propagating media with treatments on four species of green roof plants only represents a small step in balancing the research.

Most green roof media research has focused on the effects that depth has on plant growth and survival (Rowe et al., 2012; Thuring and Berghage, 2010). While plant success may improve with increased depth there are several cost considerations, including roof strength. The weight of a 3-inch deep system is about 20 pounds per square foot, including a mature plant cover. Mid-range, 5-inch, systems weigh approximately 34 pounds per square foot and are compatible with wood or steel decks (Miller, 2017).

Greenhouses, unlike green roofs, are less limited by loading and depth constraints and could be an integral variable in future green roof studies. The impact of various greenhouse propagating media across a wide range of plants and with a wide range of base treatments should continue to be a worthwhile area of green roof research.

Along with spread, survival rate and growth, future studies should investigate root establishment. The success of *Dianthus* and mycorrhizal fungi in this study suggests that root establishment may be an important variable. Along with sampling root size, future studies should directly assess the impact of freezing and thawing events on plug growth and survival. While this study was conducted over a two-year period, future studies should be conducted for longer periods of time to investigate self-sowing ability of various plant species and survivability limits.

Plant species for future studies should be chosen according to the main function of the extensive green roof, whether it be environmental, economic, or socio-cultural. If the extensive green roof is highly visible, well-adapted plants should be chosen with high aesthetic value. If the extensive green roof is built mainly for ecological functions like storm water management, species such as *Sedums* and grasses should be investigated. However, if the function of the green roof is urban agriculture then appropriate crop species should be chosen (Ouellette, et al, 2013).

Finally, if future studies continue to use rating scales to determine plant vitality or aesthetics, these results will need to be obtained with a reliable rating procedure. While this study used a single rater, having future studies with multiple raters would allow for an inter-rater reliability check and therefore provide more reliable data.

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