Establishment and Persistence of Sedum spp. and Native Taxa for Green Roof Applications

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Abstract. Although the economic, environmental, and aesthetic benefits of green roofs have been recognized for decades, research quantifying these benefits has been limited—particularly in the U.S. Green roof usage and research is most prevalent in Germany, but can also be seen in several other European countries and Canada. If green roof installations are to be successful in Michigan and the rest of the U.S., then a better understanding of what specific taxa will survive and thrive under harsh rooftop conditions in this geographic area is required. Nine simulated rooftop platforms containing three commercially available drainage systems were installed at Michigan State University. Eighteen Michigan native plants planted as plugs and nine Sedum spp. planted as either seed or plugs were evaluated over three years for growth, survival during both establishment and overwintering, and visual appearance. All Sedum spp. tested were found to be suitable for use on Midwestern green roofs. Of the eighteen native plant taxa tested, Allium cernuum L., Coreopsis lanceolata L., Opatnia humifusa Raf., and Tradescantia ohiensis L. are suitable for use on unirrigated extensive green roofs in Michigan. If irrigation is available, then other native species are potential selections.

Installations of vegetated rooftop systems, commonly referred to as green roofs, have been documented since the Hanging Gardens of Babylon (Farrar, 1996). In parts of the world where wood was not available, clay and sod were used as building materials. This construction practice can be considered to be the foundation on which modern green roof systems are patterned. Several benefits can be realized from the use of green roofs. First, they reduce the quantity of runoff entering municipal stormwater management systems (Kolb, 2004; Liesecke, 1998, 1999; Rowe et al., 2003; Schade, 2000; U.S. EPA, 2003). Second, they provide insulation for buildings, thus reducing energy consumption (Eumorfo-poulou and Aravantinos, 1998; Lükenga and Wessels, 2001; Theodosiou, 2003). Third, they increase the life span of a typical roof by protecting the various roof components from damaging UV rays, extreme temperatures, and rapid temperature fluctuations (Lükenga and Wessels, 2001; Stein, 1990). Fourth, they have the potential to reduce the Urban Heat Island Effect (Dimoudi and Nikolopoulou, 2003; Wong et al., 2003). In addition, green roofs can reduce air and water pollution (U.S. EPA, 2003), enable city residents to produce their own food (Shariful Islam, 2004), increase biodiversity (Breunesein, 2004), and the aesthetic value of plants reduces stress and provides a positive influence on human well-being (Reif and Lohr, 2003).

Although these benefits have long been identified, research quantifying these benefits and suitability of various plant taxa for use on green roofs has been limited—particularly in the U.S. Green roof usage and research have been most prevalent in Germany, but can also be seen in several other European countries and Canada. Studies have been conducted utilizing simulated rooftop platforms or other methods to evaluate the success of a variety of taxa, both herbaceous and woody, under various conditions (Durham et al., 2004; Emilsson, T. 2003; Heinz, 1985; Koehler, 2003). The physical properties, suitability for plant growth, and cost of various substrates has also been examined (Dunnett and Nolan, 2004; Kolb and Schwarz, 1984). Heinz (1985) compared combinations of various Sedum spp., grasses, and herbaceous perennials, planted at two substrate depths in simulated roof platforms to determine which taxa were best suited for a rooftop environment. Sedum spp. outperformed the other taxa except when planted in combination with grass taxa in substrate deeper than 10 cm that was kept moist. Decreased plant performance in shallower substrate is probably due to rapid, frequent changes in substrate temperature that causes plants to constantly shift in and out of dormancy (Boivin et al., 2001). Other studies support the suitability of low-growing Sedum spp. for use in green roofs due to superior survival in substrate layers as thin as 2 to 3 cm (Gómez-Campo, 1994; Gómez-Campo and Gómez-Tortosa, 1996).

Native taxa have potential for use on green roofs due to their adaptability to the existing climate. Coreopsis lanceolata and Rudbeckia hirta are two Midwest native taxa that have been shown to be more successful than traditional grass taxa in establishing cover in landfills (Sabre et al., 1987). These two taxa are also a viable alternative to grass in the production of sod due to their lack of a deep taproot and ability to withstand transplanting (Johnson and Whitwell, 1997). One concern in regards to native taxa, particularly grasses, is the potential fire hazard resulting from accumulation of dry matter associated with their natural life cycle.

If green roof installations are to be successful in the wide range of climatic conditions present in the U.S., then a better understanding of what specific taxa will survive and thrive in those geographic locations is needed. Taxa suitable for Germany are not necessarily ideal for the midwestern U.S. because of our greater extremes in winter and summer temperatures. Therefore, the objectives of this study were to compare propagation method, rate of establishment, growth, and persistence of various plant taxa grown on roof platforms with three commercially available drainage systems in Michigan.

Fig. 1. Graphic representation of an individual model scale roof platform used to evaluate plant taxa. Illustration by Marlene Cameron.
Materials and Methods

Platforms: Nine roof platforms (ChristenDETROIT Roofing Contractors, Detroit, Mich.) measuring 2.4 × 2.4 m were installed at Michigan State University (East Lansing, Mich.). Platforms were divided into three self-contained sections measuring 0.8 × 2.4 m (Fig. 1). Each platform duplicated a typical green roof construction with respect to insulation, protective layers, and waterproofing membranes. A wood frame housed each system with sides extending 20 cm above the platform floor. Lining the floor of each platform was 3.8 cm of “E’NRG’Y 2” insulation board (Johns Manville, Denver, Colo.) composed of a closed cell polyisocyanurate foam core bonded in the foaming process to universal reinforced facers. Over this layer was a Siplast systems use a drainage layer about 3.5 cm thick and consists of small, interconnected cups designed to provide additional water retention capability to the system. Sarnafil uses a cross hatch drainage system about 1 cm in thickness that allows water that leaches through the substrate to exit the roof with no retention. Platforms were set at a 2% grade with the top edge of each platform elevated about 1.4 m from ground level and were oriented with the low end of the slope toward the south to maximize sun exposure.

Substrate. Each platform received 10 cm of growing substrate. The substrate was composed of 60% heat-expanded slate (PermaTill; Carolina Slate; Salisbury, N.C.) with a particle size ranging from 7.9 to 9.5 mm, 25% USGA (U.S. Golf Association) grade sand, 5% aged compost, and 10% Michigan peat. Compost consisted of aged poultry manure (Herbruck’s Poultry Ranch; Saranac, Mich.) and composted yard waste (Charter Township of Ypsilanti; Ypsilanti, Mich.) mixed in a 2:1 ratio (v:v). Substrate bulk density, capillary pore space, noncapillary pore space, infiltration rate, and water holding capacity at 0.1 MPa were 1.3 g cm⁻³, 19.9%, 21.4%, 51.6 cm h⁻¹, and 17.1%, respectively (A & L Laboratories, Fort Wayne, Ind.). Saturated weight was equal to 1.5 g cm⁻³.

Plant material. Within the platform partitions, three groups of plants were cultivated to evaluate the effect of drainage system on plant establishment, growth, and survival (Fig. 1). One group consisted of seven Sedum spp. propagated from seed. Taxa included S. acre L., S. albus L., S. kamtschaticum Fis. & Mey., S. ellacombeanum Praeger, S. pulchellum Asn., S. reflexum L., and S. spurium Bieb. ‘Coccineum’. Seed was applied at a rate of 1.0 g m⁻² and was mixed with 250 mL m⁻² of dry sand to ensure even distribution. All seed was obtained from Jelitto Staudensamen, GmbH (Schwarzmestdt, Germany). A second group consisted of two Sedum spp. planted from plugs (116.3 cm², 38/flat): S. middendorffianum Trin. et Rup. and S. spurium L. ‘Royal Pink’. These plugs were supplied by Hortech, Inc. (Spring Lake, Mich.) and the study contained 108 plugs of each taxa. The third group consisted exclusively of 18 taxa of Michigan native plants: Agastache foeniculum J. Clayton ex Gron. (lavrader hyssop), Allium cernuum L. (nodding wild onion), Aster laevis L. (smooth aster), Careopsis lanceolata L. (lanceleaf coreopsis), Fragaria virginiana Duchesne (wild strawberry), Juncus effusus L. (spikerush), Koeleria macrantha Regel (junegrass), Liatris aspera Gaertn. ex Schreb. (rough blazingstar), Monarda fistulosa L. (bergamot), Monarda punctata L. (horsemint), Oenothera humifosa Raf. (prickly pear), Petasites hirsutus Purpureum Rhyd. (purple prairie clover), Potentilla anserina L. (silver feather), Rudbeckia hirta L. (black-eyed Susan), Schizachyrium scoparium Nash (little bluestem), Solidago rigida L. (stiff goldenrod), Sporobolus heterolepis A. Gray (prairie dropseed), and Tradescantia ohiensis L. (spiderwort). All native plants were planted from plugs (150.8 cm², 38/flat) obtained from Wildtype Nursery Inc. (Mason, Mich.) except for Potentilla anserina, which was planted from stolons supplied by Hortech, Inc. There were 27 plugs of each native taxa included in the study. All plugs and seed were planted on the platforms 15 June 2001.

Each of the three plant groups (Sedum spp. plugs, native plugs, and Sedum spp. seed) were randomly assigned to one of three platform sections (Fig. 1). Each native plant section consisted of 18 taxa randomly assigned to one of three platform sections at a rate of 30 g m⁻² 66 d after initiation of the experiment to promote growth. Final growth measurements and survival data were recorded during October 2003 and May 2004, respectively. A snapshot of volumetric substrate moisture (m³ m⁻³) was measured at depths of 1.0 cm and 9.0 cm at the center of each subsection (low end of slope, middle of slope, high end of slope) within each platform on day 104 (Sept. 27) using a soil moisture sensor (Theta Probe model ML2X; Delta-T Devices Ltd., Cambridge, U.K.). The probe was calibrated to measure mineral soil moisture within a working range of 0.05-0.006 m³ m⁻³. Values reported are the means of three measurements. Substrate temperatures (locations the same as for soil moisture) were recorded on day 106 using a thermocouple (Barnant Company, Barrington, Ill.). Ambient air temperature and precipitation data were compiled from the Michigan Automated Weather Network’s (MAWN) East Lansing weather station. Air temperatures were recorded at 1.5 m from the ground.

Data analysis. To compare plant growth indices, a mixed model was fit with repeated measures and fixed effects of system design, time, and platform section (PROC GLM SAS version 8.02, SAS Institute, Cary, N.C.). An autoregressive covariance structure was used and platform was treated as a random effect. To compare visual ratings, a generalized linear model with a multinomial error structure was fit with system design as a fixed effect (PROC GENMOD). Differences between system designs were tested within each taxa using chi-squared tests. Seeding coverage was fit to a mixed model with fixed effects of location, system design, and time using repeated
measures with an unstructured covariance matrix. Seedling coverage values were transformed before analysis using an arcsine square root transformation to ensure homogeneity of variance and normality. In all analyses, Tukey-Kramer adjustments were made to test for pairwise differences.

**Results and Discussion**

**Plant establishment from seed.** During establishment, seed germination and subsequent plant coverage was affected by position on the platform and varied by drainage type. In general, faster seedling coverage for *Sedum* was found at the low end of the slope probably due to higher substrate moisture levels. After spring growth the following year, 100% *Sedum* coverage was observed in all seeded sections of all platforms. At this time, the two dominant species were *S. acre* and *S. album*. This implies that these two species are relatively aggressive spreaders relative to the others tested, a phenomenon that was also observed by Durhman et al. (2004).

**Plant growth and appearance.** During the first season, growth of most native plants peaked in September, and then declined with the onset of dormancy (Fig. 2). Optimum growth and appearance during the entire first season was possible because irrigation was provided during the plant establishment phase. Supplemental irrigation was much reduced during the second season and was terminated completely by 10 July of the second season. Therefore, after this date plants had to rely on natural rainfall, the likely scenario on most extensive green roofs.

After irrigation was terminated in 2002, plants from many of the native taxa died or went into dormancy. In the second season, most taxa were at their peak growth and appearance in July. These drastic effects might have been reduced if no supplemental irrigation had been supplied during the entire season and the plants were allowed to grow in response to natural rainfall. However, when no irrigation was applied during 2003, none of the native plants exhibited the growth they experienced in the previous two years, except for *A. cernuum* and *O. humifosa*, which continued to increase in size. Growth of *C. lanceolata*, *J. effusus*, *K. macrantha*, *S. heterolepis*, and *T. ohiensis* was marginal. Removing irrigation had little or no effect on all of the species of *Sedum*. Both the seed propagated and plug planted *Sedum* had reached 100% coverage by June 2002.
Drainage system did not consistently affect plant growth across all taxa (Fig. 2). During 2001, A. foeniculum, C. lanceolata, F. virginiana, L. aspera, P. anserina, and S. scoparium, grew significantly less in the Hydrotect system compared to Sarnafil and Siplast. This trend continued into 2002 for F. virginiana, O. humifosa, and S. scoparium. However, in July 2002, the Hydrotect system resulted in the greatest growth for A. laevis, M. punctata, R. hirta, and S. rigida. By 2003, there was very little difference among the green roof systems except that A. cernuum exhibited the least amount of growth in Hydrotect and S. heterolepis did best in Siplast. Growing system had little or no effect on Sedum.

Few differences were observed within taxa in each drainage system and no system produced consistently higher visual ratings (Table 1). In a previous study, Kessler (1987) reported that Sedum spp. grew very well in three of four drainage systems tested with the exception being a system used by Hydrotect. Our tests showed no consistent problems with the Hydrotect system when compared to the others.

Throughout the study, S. ‘Diffusum’ and S. ‘Royal Pink’ showed the highest visual results rating of all taxa tested, as well as displaying the greatest drought tolerance after the termination of irrigation in the 2002 season. Visual ratings were not recorded on the seed propagated Sedum, but they maintained their 100% coverage even after irrigation ended. This finding supports the concept that Sedum spp. can be used in a wide variety of conditions and will grow successfully, particularly in dry areas (Gravatt and Martin, 1992; Heinz, 1985). Sedum can survive severe drought because of their method of photosynthetic carbon metabolism (Crassulacean acid metabolism) and their method of photosynthetic carbon metabolism. Sedum can survive severe drought because of their method of photosynthetic carbon metabolism (Crassulacean acid metabolism) and their method of photosynthetic carbon metabolism (Gravatt and Martin, 1992; Heinz, 1985).

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Table 2. Percent survival of taxa over three seasons (2001–04). Values indicate survival of original plugs planted.

### Table 1. Visual rating for each taxa planted from plugs by system design during July 2002 and October 2003.

| Taxa                  | July 2002 | October 2003 |
|-----------------------|-----------|--------------|
|                       | Hydrotech | Sarnafil     |
|                       | Siplast   | Hydrotech    |
|                       | Sarnafil  | Siplast      |
| Agastache foeniculum  | 2.8 ab    | 2.8 a        |
| Allium cernuum        | 2.7 ab    | 2.7 a        |
| Aster laevis          | 5.0 a     | 5.0 a        |
| Coreopsis lanceolata  | 2.8 a     | 2.8 a        |
| Fragaria virginiana   | 1.7 b     | 1.7 b        |
| Juncus effusus        | 2.6 a     | 2.6 a        |
| Koeleria macrantha    | 2.4 a     | 2.4 a        |
| Liatris aspera        | 2.8 a     | 2.8 a        |
| Monarda fistulosa     | 4.0 ab    | 4.0 ab       |
| Monarda punctata      | 2.9 a     | 2.9 a        |
| Opuntia humifosa      | 2.0 a     | 2.0 a        |
| Petoletosmon purpureum| 1.1 a     | 1.1 a        |
| Potentilla anserina    | 3.0 a     | 3.0 a        |
| Rudbeckia hirta       | 2.8 a     | 2.8 a        |
| Schizachyrium scoparium| 1.1 b     | 1.1 b        |
| Sedum Diffusum        | 4.5 a     | 4.5 a        |
| Sedum Royal Pink      | 4.4 a     | 4.4 a        |
| Solidoig rigidia      | 4.6 a     | 4.6 a        |
| Sporobolus heterolepis| 1.4 a     | 1.4 a        |
| Tradescantia ohiensis | 4.8 a     | 4.8 a        |

*Mean separation in rows between system design within each taxa were tested using chi-squared tests. P ≤ 0.05; n = 9. Tests were done individually for 2002 and 2003.*

### Table 2. Percent survival of taxa over three seasons (2001–04). Values indicate survival of original plugs planted 15 June 2001.

| Taxa                  | Survival (%) |
|-----------------------|--------------|
|                       | October 2001 | May 2002 | October 2002 | May 2003 | October 2003 | May 2004 |
| Agastache foeniculum  | 100 a        | 100 a   | 0 c         | 0 d      | 0 c         | 0 c     |
| Allium cernuum        | 96 a         | 96 a    | 96 a        | 96 a     | 96 a        | 96 a    |
| Aster laevis          | 100 a        | 100 a   | 0 c         | 0 d      | 0 c         | 0 c     |
| Coreopsis lanceolata  | 89 b         | 89 ab   | 15 bc       | 4 d      | 4 c         | 4 c     |
| Fragaria virginiana   | 70 d         | 70 c    | 0 c         | 0 d      | 0 c         | 0 c     |
| Juncus effusus        | 96 a         | 96 a    | 96 a        | 96 a     | 96 a        | 96 a    |
| Koeleria macrantha    | 100 a        | 100 a   | 22 b        | 22 b     | 7 c         | 7 c     |
| Liatris aspera        | 100 a        | 100 a   | 0 c         | 0 d      | 0 c         | 0 c     |
| Monarda fistulosa     | 96 a         | 96 a    | 96 a        | 96 a     | 96 a        | 96 a    |
| Monarda punctata      | 100 a        | 100 a   | 56 d        | 0 c      | 0 d         | 0 c     |
| Opuntia humifosa      | 100 a        | 100 a   | 100 a       | 100 a    | 100 a       | 100 a   |
| Petoletosmon purpureum| 78 c         | 78 bc   | 0 c         | 0 d      | 0 c         | 0 c     |
| Potentilla anserina    | 100 a        | 100 a   | 0 c         | 0 d      | 0 c         | 0 c     |
| Rudbeckia hirta       | 89 b         | 85 d    | 0 c         | 0 d      | 0 c         | 0 c     |
| Schizachyrium scoparium| 74 cd        | 67 c    | 0 c         | 0 d      | 0 c         | 0 c     |
| Sedum Diffusum        | 100 a        | 100 a   | 100 a       | 100 a    | 100 a       | 100 a   |
| Sedum Royal Pink      | 100 a        | 100 a   | 100 a       | 100 a    | 100 a       | 100 a   |
| Solidago rigidia      | 100 a        | 100 a   | 100 a       | 100 a    | 100 a       | 100 a   |
| Sporobolus heterolepis| 85 bc        | 81 b    | 26 b        | 11 ced   | 4 c         | 4 c     |
| Tradescantia ohiensis | 100 a        | 100 a   | 96 a        | 56 b     | 18 b        | 18 b    |

*Pairwise differences within columns were made by Tukey-Kramer adjustments. P ≤ 0.05; n = 27 for native taxa, n = 108 for Sedum spp.*
purpureum, and S. scoparium, experienced losses greater than 15% (Table 2). The hot weather that prevailed during much of the first growing season could have affected plant mortality during the establishment phase. During the summer growing season from 1 June 2001 through 1 Sept. 2001, the mean daily high air temperature was 27.0 °C. The high temperature was 35.4 °C and nine days had a high temperature greater than 32.2 °C (Fig. 3). Total natural precipitation during this time period was 149.6 mm, however, plants were irrigated the entire summer so drought was not a factor.

The termination of supplemental irrigation during the second growing season combined with another unusually warm summer was fatal to many of the native taxa (Table 2). With another unusually warm summer was not a factor. There was only 125.5 mm. warm, total precipitation during this time period was only 125.5 mm.

Cold tolerance is also an important attribute of plants for green roofs in cold climates such as Michigan. During the first winter, major losses occurred for M. punctata and S. rigidula. Thus, because of cold hardiness problems, it appears these two species are not suitable for use on Michigan green roofs or other regions with a similar climate. Rudbeckia hirta, S. scoparium, and S. heterolepis also exhibited overwintering mortality, but losses were <7%. Additional mortality occurred during the second winter to plants of C. lanceolata, T. ohiensis, and A. cernuum to seed freely and naturalize make them potential choices for extensive green roofs. Only one of the original 27 plants of C. lanceolata survived for three years, 30 plants were present in May 2004 due to reseeding in alternate locations on the platforms. Likewise, there were 17 separate clumps of T. ohiensis in May 2004, even though only five of the original plants had survived. A. cernuum also proved to be an excellent choice as 96% of the original clumps of plants were still present after three years. In addition, A. cernuum spread from 27 to 34 locations and the average number of plants per clump increased from one to 21.4. The ability of C. lanceolata, T. ohiensis, and A. cernuum to seed freely and naturalize make them potential choices for extensive green roofs. Of the nine Sedum spp. tested, all proved to be suitable for shallow substrate green roof systems.

Conclusion

Drainage system design had minimal effect on the initial growth, appearance during establishment, or mortality of the taxa tested. Ideal plant selections for extensive green roofs in northern climates such as Michigan that lack irrigation must be cold tolerant, drought resistant, have a high growth index in order to provide quick coverage, and must be self-generating by seed, root systems, or some other means. Of the species tested, all nine species of Sedum along with A. cernuum, C. lanceolata, and T. ohiensis were the most suitable for unirrigated roofs. O. humifosa survived, but lacked the ability to provide quick surface coverage. Further experiments are necessary to determine the soil moisture
requirement to sustain native perennials and to determine whether these taxa can tolerate the low winter temperatures that are typical of the Midwest climate.

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