Effect of Substrate Depth and Planting Season on *Sedum* Plug Survival on Green Roofs[1]

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Abstract

Green roofs, a roofing technology that entails growing plants on rooftops, provide many benefits such as improved stormwater management, energy conservation, mitigation of the urban heat island effect, increased longevity of roofing membranes, reduction in noise and air pollution, and improved aesthetics. Plants on rooftops are more susceptible to extremes in temperature and drought due to their shallow substrate and elevation above ground. Because of these unfavorable growing conditions, plant selection and season of establishment are critical. The major objective of this study was to quantify the effect of substrate depth and planting season on successful establishment of plugs of *Sedum* species on green roofs. Plugs of nine species of *Sedum* were planted in East Lansing, MI, in autumn (September 20, 2004) or spring (June 8, 2005) and then evaluated for survival on June 1, 2005, and June 1, 2006, respectively. Overall, spring planting exhibited superior survival rates (81%) compared to autumn (23%) across substrate depths. *Sedum cauticola* 'Lidakense', *S. floriferum*, and *S. sexangulare* were not affected by season of planting. *Sedum* cauticola barely survived at any substrate depth or planting season, whereas the latter two exhibited nearly 100% survival regardless of planting season. All other species had superior survival percentages when planted during spring.

Index words: vegetated roofs, stonecrop, extensive green roof.

Species used in this study: Crooked stonecrop (*Sedum* L. 'Angelina'); stonecrop (*Sedum cauticola* Praeger 'Lidakense'); Kamtschatka stonecrop (*Sedum floriferum* Fisch.); Spanish stonecrop (*Sedum hispanicum* L.); European stonecrop (*Sedum ochroleucum* Chaix); stringy stonecrop (*Sedum sarmentosum* Bunge); pale stonecrop (*Sedum sediforme* (Jaquin) Pau); tasteless stonecrop (*Sedum sexangulare* L.); and creeping sedum (*Sedum spurium* Marschall von Bieberstein 'John Creech').

Significance to the Nursery Industry

Plant selection and season of establishment for green roofs is critical to achieve project success. Selected species must be able to withstand extreme environmental conditions — primarily temperature and water availability. Because of their tolerance to drought and shallow substrates, species in the genus *Sedum* are frequently used on green roofs. Substrate depth and season of planting influenced success, but results varied among species tested. For Midwestern climates, *S. floriferum* and *S. sexangulare* are recommended for autumn establishment while *S. cauticola* 'Lidakense' should be avoided regardless of planting season. Results of this study are of use to green roof designers and installation contractors, as well as to nursery's that provide the plant material.

Introduction

Buildings cover an estimated 37,540 km^2 (14,494 mi^2) in the continental United States (8). On many new and existing roofs, conventional roofing materials are being replaced with green roofs, or vegetated roofs, because of the many benefits they can provide. Placing plants on rooftops can improve stormwater management, conserve energy, mitigate the urban heat island effect, increase the lifespan of roofing membranes, reduce noise and air pollution, and improve aesthetic appeal (4, 10). Many local governments are encouraging green roof implementation in the form of tax credits or incentives (15, 22). Perhaps as a result of these benefits and incentives, square footage of green roofs in the United States increased 81% between 2004 and 2005 to total an area of 199,703 m^2 (2,149,585 ft^2) (11).

Green roofs are categorized as 'intensive' or 'extensive' systems. Intensive green roofs are designed to be similar to landscaping found at natural ground level, and as such require substrate depths greater than 15.2 cm (6 in) and have 'intense' maintenance needs. By contrast, extensive green roofs use shallower media depths (less than 15.2 cm (6 in)) and require minimal maintenance. Due to building weight restrictions and costs, shallow substrate extensive green roofs are much more common than deeper intensive roofs. Therefore, the focus of this paper is on extensive green roofs.

As green roof implementation continues, plant selection for this harsh habitat is critical. Plants selected must survive extremes in climate and roof microclimate. Green roofs are more likely to experience drought due to shallow substrates, high temperatures, and windy conditions. Because of their tolerance to drought and shallow substrates, a mix of species in the genus *Sedum* are frequently used (4). *Sedum* spp. can be established directly upon the green roof substrate via seed, plugs, or cuttings. Plugs have the advantage of a developed root system prior to roof placement, but this root system must grow into the roof substrate before they will become established. Alternatively, plants can be pre-grown at ground level in the form of a blanket, mat, or tray and then placed on the roof. This latter method is often more expensive and has the logistical disadvantage of hauling the pre-grown vegetation up to the roof, but offers immediate gratification in the form of 100% coverage. Even so, the majority of green roofs are planted with plugs.

For many species, including *Sedum*, substrate depth influences rate of substrate coverage and plant growth (7). Deeper substrates are beneficial for both increased water holding capacity (23, 24) and as a buffer for overwintering survival as shallow substrates are more subject to fluctuations in tem-

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perature (1). Despite the cultural limitations of shallow substrate depths, they are often desirable because buildings must be structurally strong enough to support the added weight of the green roof.

Season of establishment has the potential to impact initial plant survival, growth, and coverage on green roofs as well. In the nursery industry, autumn transplanting has been shown to be superior in terms of establishment success for many woody species (12, 13). In contrast, grasses have limited establishment success when transplanted in autumn (18, 21). For herbaceous perennials, it depends on the species and climate as to whether spring or autumn transplanting is best for initial establishment. Autumn has the potential to be successful because the soil is still warm and moist which allows roots to establish quickly (2) while spring transplanting offers more time for roots to become established before the next winter (16). In many climates, summer transplanting is only feasible if irrigation is available.

Initial plant establishment research on green roofs to date have focused on watering regimes (5, 6, 7, 24), fertilizer rates (14, 20), substrate depth (5, 7, 24), substrate composition (19, 20), drainage systems (17), or propagule type (14, 17). To our knowledge, no studies have focused on season of establishment. Therefore, the objective of this study was to quantify the effect of both substrate depth and planting season on the success of *Sedum* plug establishment on extensive green roofs.

Table 1. Physical and chemical properties of substrate.

Component	Unit
Total Sand	86.00%
Very Coarse Sand (1-2 mm)	2.62%
Coarse Sand (0.5-1 mm)	20.08%
Medium Sand (0.25-0.5 mm)	41.68%
Fine Sand (0.10-0.25 mm)	19.92%
Very Fine Sand (0.05-0.10 mm)	1.70%
Silt	10.00%
Clay	4.00%
Bulk Density	1.37 g/cm^3
Capillary Pore Space	22.05%
Non-Capillary Pore Space	10.30%
Water Holding Capacity at 0.01 MPa	16.05%
pH	7.9
Conductivity (EC)	1.38 mmho/cm
Nitrate	47 ppm
Phosphorus	3.6 ppm
Potassium	23 ppm
Calcium	388 ppm
Magnesium	38 ppm
Sodium	77 ppm
Sulfur	73 ppm
Boron	0.7 ppm
Iron	8.2 ppm
Manganese	2.6 ppm
Zinc	6.4 ppm
Copper	1.0 ppm

Analysis per A&L Great Lakes Laboratories, Inc., Ft. Wayne, IN.

Materials and Methods

Green roof testing platforms. Three raised roof platforms with dimensions of 2.44 × 2.44 m (8.0 × 8.0 ft) were utilized at the Michigan State University Horticulture Teaching and Research Center (East Lansing, MI). Each platform replicated a commercial green roof, including insulation, protective and waterproofing membrane layers. Construction details are outlined per VanWoert et al. (23).

The wood-framed platforms included sides that extended 20.3 cm (8.0 in) above the platform deck. Each platform was divided into three equal sections measuring 0.77 × 2.40 m (2.53 × 7.87 ft) using wood dividers. The platform sides and dividers were also covered with waterproofing membrane. Each platform was set at a 2% slope and placed with the low end of the slope facing south to maximize sun exposure.

Drainage system and vegetation carrier. Each platform was constructed with a Xero Flor XF108 drainage layer (Wolfgang Behrens Systementwicklung, GmbH, Groß Ippener, Germany) installed over the waterproofing system which allowed excess water to flow off the roof. For additional water holding capacity, a 0.75 cm (0.26 in) thick moisture retention fabric (Xero Flor XF158) capable of retaining 1,200 g/m^2 (0.03 gal/ft^2) of water was placed over the drainage layer. Above the retention fabric was the vegetation carrier (Xero Flor XF301).

Treatments and plant establishment. Growing substrate (Table 1) was placed on the vegetation carrier at depths of 4, 7, or 10 cm (1.57, 2.75, or 3.93 in). Substrate treatments were blocked by arranging each depth randomly on each platform, replicated three times (a randomized complete block design (RCB)).

For autumn establishment, nine *Sedum* species (*Sedum* L. 'Angelina' (crooked stonecrop), *Sedum cauticola* Praeger 'Lidakense' (stonecrop), *Sedum floriferum* Fisch. (Kamtschatka stonecrop), *Sedum hispanicum* L. (Spanish stonecrop), *Sedum ochroleucum* Chaix (European stonecrop), *Sedum sarmentosum* Bunge (stringy stonecrop), *Sedum sediforme* (Jaquin) Pau (pale stonecrop), *Sedum sexangulare* L. (tasteless stonecrop), and *Sedum spurium* Marschall von Bieberstein 'John Creech' (creeping sedum)) were sown from seeds into plug trays (138.6 cm^3 (8.5 in^3); 48/flat) in June 2004. Plugs were planted on September 20, 2004, 10 cm (3.93 in) from platform edges with four plants in a row 17 cm (6.69 in) apart. Each row was 20 cm (7.87 in) apart, resulting in twelve rows per. Each plant species was planted three times randomly in each section. All plots were fertilized on September 21, 2004, with Nutricote controlled release fertilizer 18–6–8 type 120 (Agrivert, Webster, TX) at 100 g/m^2, (0.33 oz/ft^2) resulting in 180.0 g (6.3 oz) applied to each section. Plants were watered to field capacity by hand on the day of initial planting and twice a week for three weeks thereafter. No further artificial irrigation was provided.

For spring establishment, the same nine *Sedum* species were obtained from Emory Knoll Farms (Street, MD) as plugs (120 cm^3 (7.3 in^3); 72/flat) and were planted on June 8, 2005, as outlined above. Each plant species was planted four times randomly in each section. Plugs were watered to field capacity by hand the day of planting. No further artificial irrigation was provided. All plots were fertilized at time of planting as before.

Data collection and analysis. Plug survival was evaluated on June 1, 2005, and June 1, 2006, for autumn and spring establishment respectively. Plugs were considered alive if

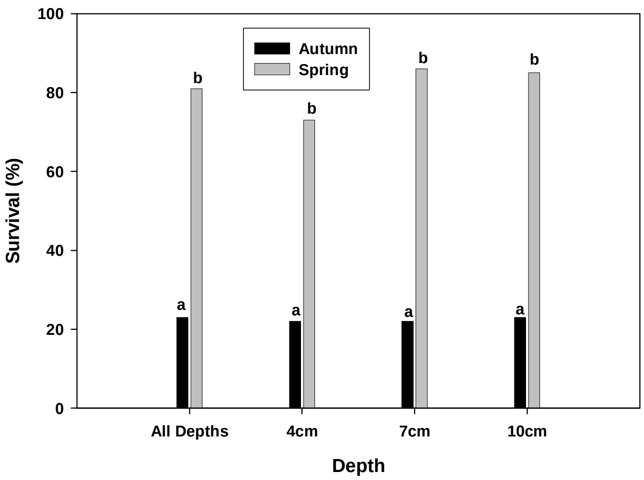

Fig. 1. Percent survival of *Sedum* species by planting season and substrate depth.

they exhibited any green tissue upon visual analysis. In the absence of any green tissue, the plant was considered dead.

Data were analyzed as mean plant survival using non-parametric Kruskal-Wallis tests (PROC NPAR1WAY, SAS version 8.02, SAS Institute, Cary, NC). Significant differences between treatments were determined using multiple comparisons of the Chi-Square statistic ($\alpha = 0.05$).

Results and Discussion

Overall, spring planting exhibited superior survival rates (81%) compared to autumn (23%) (Fig. 1). This is probably because autumn planting had at most five weeks of establishment time before the first frost, whereas those planted in spring had over 16 weeks. During this time, roots had a chance to grow out of the plug into the green roof substrate, which would help prevent heaving of plugs during the winter.

Substrate depth did not influence survival for the three depths tested, but season of planting was significant across all depths. When averaged across species, survival percentages were 22, 22, and 23 for autumn and 73, 86, and 85 for spring at depths of 4 cm (1.57 in), 7 cm (2.75 in), and 10 cm (3.93 in), respectively ($\alpha = 0.05$) (Fig. 1). For all depths combined, most species exhibited significant differences between autumn and spring establishment (data not shown). The only species not affected by season of planting were *S. cauticola* ‘Lidakense’, *S. floriferum*, and *S. sexangulare*; the former barely survived regardless of substrate depth or planting season and the latter two survived nearly 100% in all cases (Table 2). All other species had superior survival percentages in spring plantings. The same is true for individual substrate depths (Table 2).

One factor that could possibly be effecting plug overwintering survival is the temperature fluctuations of the substrate. Boivin et al. (1) found that shallower green roof substrates experienced much larger temperature fluctuations than deeper substrates. Root systems are more susceptible to cold damage in shallow depths (1) as roots are generally not as cold tolerant as the tops of plants (25). These rapid changes influence plant growth and thus initial establishment.

While the limited amount of time for root establishment for autumn transplants may have been a large factor in overwintering success, if the plugs survived on these raised platforms (which had ambient air below the decking), then they would likely survive on a heated building. A roof on a heated building would likely have heat escaping from the building at the root zone level, keeping roots warmer. This artificial microclimate could extend the growing season by days if not weeks, allowing roots additional establishment time before true dormancy occurs. While using a deeper substrate for fall establishment may minimize these fluctuations and enhance plug survival, it will likely increase the cost of the green roof and pose possible building weight restrictions problems.

In addition, species hardiness may have played a role in overwintering success. East Lansing, MI, is classified as Zone 5 on the USDA plant hardiness map, a value corresponding to an average minimum temperature between –26 to –29C (–20 to –10F) (3). Those species that did best in autumn establishment are also those species with the lowest USDA hardiness zone ratings. Two species tested here with hardiness zones greater than 5 (*S. hispanicum* and *S. sediforme*) survived our Zone 5 climate when planted in the spring and one species (*S. cauticola* ‘Lidakense’) classified as hardy to Zone 4 did not survive in either planting season, both of which confirm the variability of roof microclimates. In addition, because *S. cauticola* ‘Lidakense’ did poorly in both planting seasons, it is possible that the hardiness zone for this species has been assigned incorrectly. Species are typically assigned

Table 2. Mean survival percentage of *Sedum* species by substrate depth for fall and spring establishment.

	Percent survival by depth, in cm					
	10.0		7.0		4.0	
Species	Fall	Spring	Fall	Spring	Fall	Spring
S. ‘Angelina’	0a[z]	100b	11a	100b	33a	67b
S. cauticola ‘Lidakense’	0a	8a	0a	0a	0a	0a
S. floriferum	100a	100a	89a	100a	100a	100a
S. hispanicum	0a	83b	0a	92b	0a	83b
S. ochroleucum	0a	83b	0a	83b	0a	75b
S. sarmentosum	0a	100b	0a	100b	0a	83b
S. sediforme	0a	92b	0a	100b	0a	50b
S. sexangulare	100a	100a	89a	100a	67a	100a
S. spurium ‘John Creech’	11a	100b	11a	100b	0a	100b

[z]Lowercase letters denote comparisons between seasons within individual depths and species by Chi-Square ($\alpha = 0.05$, n = 27).

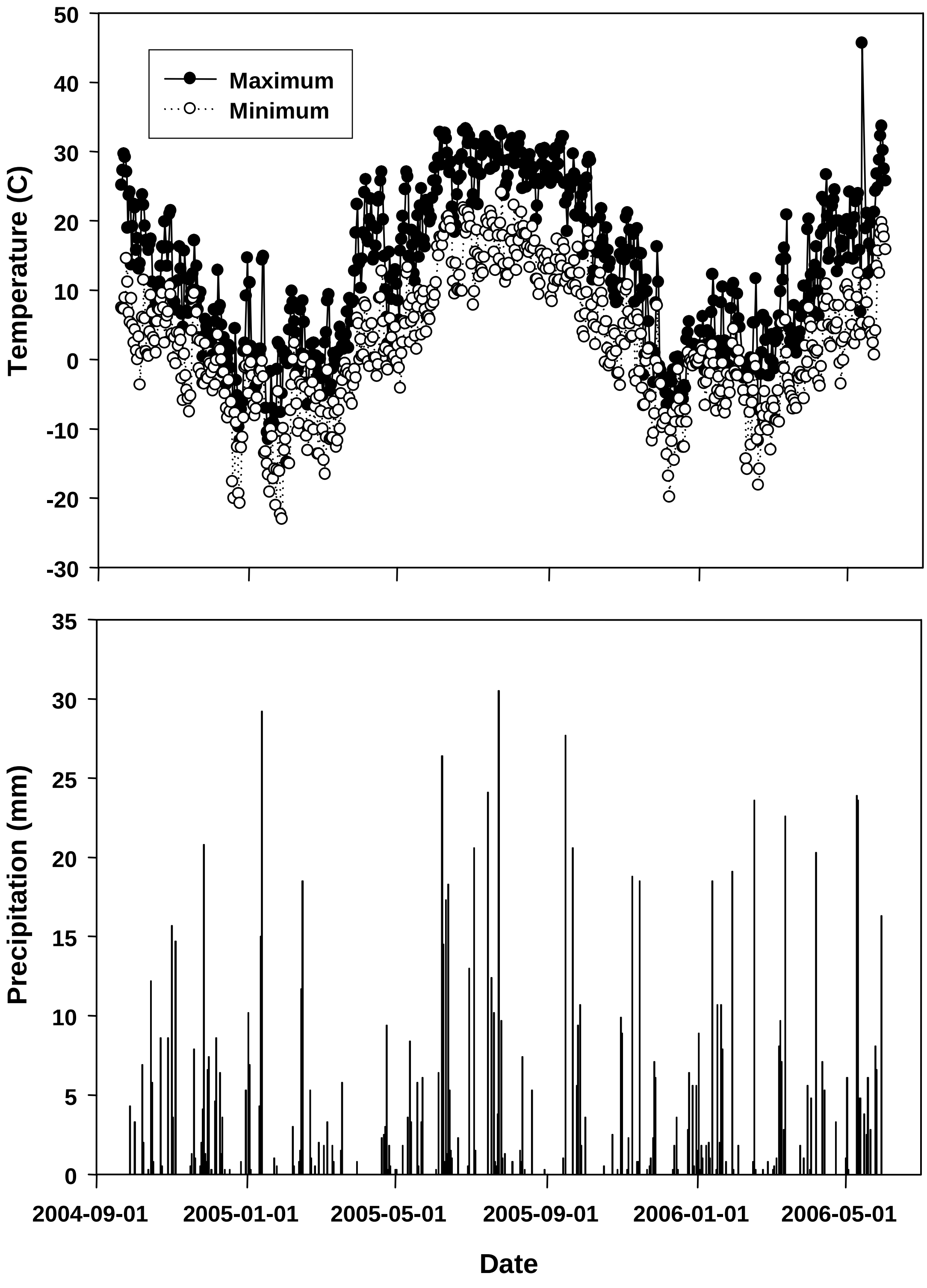

Fig. 2. Daily maximum and minimum temperatures (C) and precipitation (mm) throughout the study (September 20, 2004, to June 1, 2006). Data are from the Michigan Automated Weather Network's East Lansing weather station located adjacent to the research site.

a hardiness zone based on observation only or based on how related species have performed in the past. Hardiness zones are also meant for plants growing at ground level. In our study, the use of raised roof platforms likely lead to the entire root zone being frozen regardless of substrate depth due to the ambient air below the platform. This may possibly explain why depth was not a significant factor for survival. Winter air temperatures between the two planting times were similar, with the exception that January 2006 was much warmer than January 2005 (Fig. 2).

Although the depths tested here did not influence overwintering survival or initial establishment, subsequent growth and coverage is dependent on depth (7, 9). Rapid coverage is important because high groundcover density will reduce possible erosion problems, inhibit weeds, and provide a more aesthetically pleasing roof. An earlier autumn planting date may have allowed more time for additional root growth into the green roof substrate. This would reduce the tendency for the plugs to heave out of the substrate during winter exposing the root system to the air.

These results apply to climates similar to Michigan and it is likely that fall establishment would be more successful in warmer climates. In addition, it is also likely that larger plugs may be more successful for autumn plantings, although this would be more expensive. Since the majority of extensive green roofs are established by plugs, perhaps the greater cost of larger plugs would be offset by higher plant survival rates. Depending on planting distance it usually takes over a year to reach 100% coverage, so earlier establishment, subsequent growth, and overwintering survival are critical in decreasing the amount of time for green roofs to reach maturity.

Of the *Sedum* spp. tested, most survived in greater numbers when established in the spring relative to autumn. If autumn establishment of these species is required in a similar climate to Michigan, then ample quantities of *S. floriferum* and *S. sexangulare* should be included in the species mix due to their superior overwintering success. *Sedum cauticola* 'Lidakense' should be avoided in this climate due to its limited survival in either spring or autumn plantings. All species may have survived in greater numbers on a roof over a heated building. Further research should evaluate the potential of summer establishment for these species.

Literature Cited

1. Boivin, M., M. Lamy, A. Gosselin, and B. Dansereau. 2001. Effect of artificial substrate depth on freezing injury of six herbaceous perennials grown in a green roof system. HortTechnology 11:409–412.

2. Brickell, C. and J.D. Zuk. 1997. The American Horticultural Society A–Z Encyclopedia of Garden Plants. DK Publishing, Inc. New York.

3. Cathey, H.M., 1990. USDA Plant Hardiness Zone Map. USDA Agric. Res. Serv. Misc. Publ. 1475.

4. Dunnett, N. and N. Kingsbury. 2004. Planting Green Roofs and Living Walls. Timber Press, Inc., Portland, OR.

5. Dunnett, N. and A. Nolan. 2004. The effect of substrate depth and supplementary watering on the growth of nine herbaceous perennials in a semi-extensive green roof. Acta Hort. 643:305–309.

6. Durhman, A., D.B. Rowe, and C.L. Rugh. 2006. Effect of watering regimen on chlorophyll fluorescence and growth of selected green roof plant taxa. HortScience 41:1623–1628.

7. Durhman, A., N.D. VanWoert, D.B. Rowe, C.L. Rugh, and D. Ebert-May. 2004. Evaluation of Crassulacean species on extensive green roofs. p. 504–517. *In*: Proc. of 2nd North American Green Roof Conference: Greening Rooftops for Sustainable Communities, Portland, OR. June 2–4, 2004. The Cardinal Group, Toronto.

8. Elvidge, C., C. Milesi, J. Dietz, B. Tuttle, P. Sutton, R. Nemani, and J. Vogelmann. 2004. U.S. Constructed Area Approaches the Size of Ohio. EOS, Transactions, American Geophysical Union 85(24):233–240.

9. Getter, K.L. 2006. Evaluation of plant species and slope runoff on extensive green roofs. M.S. Thesis. Michigan State University, East Lansing, MI.

10. Getter, K.L. and D.B. Rowe. 2006. The role of extensive green roofs in sustainable development. HortScience 41:1276–1285.

11. Green Roofs for Healthy Cities. 2006. Final Report Green Roof Industry Survey 2004 & 2005. Green Roofs for Healthy Cities. Toronto, Ontario.

12. Hanson, A., J.R. Harris, and R. Wright. 2004. Effects of transplant season and container size on landscape establishment of *Kalmia latifolia* L. J. Environ. Hort. 22:133–138.

13. Harris, J.R., J. Fanelli, and P. Thrift. 2002. Transplant timing affects early root system regeneration of sugar maple and northern red oak. Hortscience 37:984–987.

14. Kircher, W. 2004. Annuals and *Sedum*-cuttings in seed-mixtures for extensive roof gardens. Acta Hort. 643:301–303.

15. Liu, K. and B. Baskaran. 2003. Thermal performance of green roofs through field evaluation. p. 273–282. *In*: Proc. of 1st North American Green Roof Conference: Greening Rooftops for Sustainable Communities, Chicago. May 29–30, 2003. The Cardinal Group, Toronto.

16. MacKenzie, D.S. 1997. Perennial Ground Covers. Timber Press, Portland, OR.

17. Monterusso, M.A., D.B. Rowe, and C.L. Rugh. 2005. Establishment and persistence of *Sedum* spp. and native taxa for green roof applications. HortScience 40:391–396.

18. Page, H.N. and E.W. Bork. 2005. Effect of planting season, bunchgrass species, and neighbor control on the success of transplants for grassland restoration. Restoration Ecology 13:651–658.

19. Panayiotis, N., T. Panayiota, and C. Ioannis. 2003. Soil amendments reduce roof garden weight and influence the growth of Lantana. HortScience 38:618–622.

20. Rowe, D.B., M.A. Monterusso, and C.L. Rugh. 2006. Assessment of heat-expanded slate and fertility requirements in green roof substrates. HortTechnology 16:471–477.

21. Steed, J. E., and L. E. DeWald. 2003. Transplanting sedges (Carex spp.) in southwestern riparian meadows. Restoration Ecology 11:247–256.

22. Taube, Benjamin. 2003. City of Atlanta GreenRoof Demonstration Project. p. 57–62. *In*: Proc. of 1st North American Green Roof Conference: Greening Rooftops for Sustainable Communities, Chicago. May 29–30, 2003. The Cardinal Group, Toronto.

23. VanWoert, N.D., D.B. Rowe, J.A. Andresen, C.L. Rugh, R.T. Fernandez, and L. Xiao. 2005. Green roof stormwater retention: Effects of roof surface, slope, and media depth. J. Environ. Quality 34:1036–1044.

24. VanWoert, N.D., D.B. Rowe, J.A. Andresen, C.L. Rugh, and L. Xiao. 2005. Watering regime and green roof substrate design affect *Sedum* plant growth. HortScience 40:659–664.

25. Wu, Y., D. Cosgrove, B. Davies, B. Sharp. 2000. Adaptation of roots to low water potentials by changes in cell wall extensibility and cell wall proteins. J. Exp. Botany 51:1543–1553.