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SELECTION OF PLANT SPECIES AND SPECIES COMBINATIONS FOR NORTHERN CLIMATES

Katherine Vinson[1], Dr. Youbin Zheng[1,2]

[1]School of Environmental Sciences, University of Guelph, Guelph, Ontario, Canada / [2]Vineland Research and Innovation Centre, Vineland, Ontario, Canada

Abstract

Two trials were conducted on a rooftop in southwestern Ontario, Canada to evaluate plant performance and species compatibilities using a tray production system. Objectives were to determine the suitability of various species for green roof projects in northern climates, appropriateness of the species for trays, species compatibilities, and the success of three *Sedum* species in partial shade. Highly suitable species were *Perovskia atriplicifolia* 'Little Spire', *Liatris spicata* 'Kobold', *Helictotrichon sempervirens*, *Artemisia stelleriana* 'Silver Brocade', *Solidago rugosa* 'Fireworks', *Nepeta xfaassenii* 'Walker's Low', *Bouteloua gracilis*, *Microbiota decussata*, *Juniperus communis* 'Green Carpet', *J. horizontalis* 'Icee Blue', and *J. procumbens* 'Nana' in full sun and *Lamiastrum galeobdolon* 'Herman's Pride' in partial shade. Unsuitable species were *Euphorbia myrsinites*, *Panicum virgatum* 'Heavy Metal', *Stachys byzantina*, and *Deschampsia flexuosa* in full sun and *Pulsatilla vulgaris* in partial shade. All surviving species were appropriate for the trays. The most compatible species were *L. galeobdolon* 'Herman's Pride' and *Sedum album* 'Coral Carpet'. The most incompatible species were *P. vulgaris*, *Campanula carpatica* 'Blue Clips', *D. flexuosa*, and most evergreen species, with their associated *Sedum* spp. *S. album* 'Coral Carpet' displayed passive behaviour in partial shade, whereas both *S. sexangulare* and *S. spurium* 'Green Mantle' displayed aggressive behaviour.

Introduction

Awareness of green roofs is spreading, much to the liking of companies partaking in the green roof industry; however, in order for these companies to meet the demands of a growing market and in order for North America to better its commitment to sustainability, all components and maintenance procedures of green roofs must be studied and improved for success.

This is important for maintaining the pioneering green roof by-laws, such as that of Toronto where its by-law requires every new building with at least 2,000 square meters of total floor area to incorporate a green roof that covers a certain percentage of the roof area, depending on the size of the roof (3). Having successful green roofs may help reduce any risk of by-law cancellation due to failure or disappointing results of the mandatory installations.

Some previous green roof research has focused, at least in part, on following the German standards described by The Landscape Development and Landscaping Research Society e. V. (6). However, many of these standards are not always applicable outside of Germany simply due to the difference in climatic conditions (5). Attention needs to be focused on customizing green roofs specifically for regions in northern climates in the western hemisphere. North America lags behind Europe for instance, in terms of its experience with green roofs, (5), and needs to expand this experience so that the green roof popularity will not fade. By maintaining this popularity, the concept of green roofs will become less foreign to the general public, thus creating a larger market and furthering the spread of green roof awareness. Oberndorfer et al (11) explain that the general public is coming to realize all the benefits associated with green roofs. In addition, with improved components, more customers are likely to be attracted since more options are available to them (2), such as a broader selection of plant species.

The selection of species is not only important for the purpose of drawing interest from potential customers, but also to the overall biological health of the green roof. Having a diverse collection of plant species on a green roof means that more habitats could be created for local wildlife (4). Since more plant species are involved, there will be more opportunities to create year round visual interest and more planting designs will become possible (10). In addition, species diversity helps withstand pests and diseases better than monocultures (1) and therefore it may help reduce the risk of plant loss.

Finally, it is important to select species that are not only well-suited for the green roof system (e.g. mat, tray, or monolithic systems), but that are also compatible among each other under the ambient growing conditions (e.g. lighting, temperature, and wind).

This experiment studied a wide range of species and species combinations which will be used to improve the selection of plant species available for green roof applications. The objectives were to determine: 1) the suitability of various plant species for use in green roof projects in northern climates, 2) the appropriateness of the species chosen for a tray system, and 3) the compatibilities between these species. In addition, it was necessary to examine some species under full sun settings and some under partial shade settings to uncover the potential success of the plants when subjected to common roof top conditions. A fourth objective arose from this: 4) to determine the overall success of three *Sedum* spp. under partial shade conditions.

Materials and Methods

Experiment setup. This study was performed on the roof of the five-storey Science Complex building at the University of Guelph in Guelph, Ontario, Canada. Plant materials were either donated by LiveRoof® Ontario Inc. (Mount Brydges, ON, Canada) or Sheridan Nurseries (Georgetown, ON, Canada), or purchased from a local garden centre. LiveRoof® Deep trays and LiveRoof® standard growing substrate were used in this study. These trays have a total substrate depth of six inches, which can be classified as either extensive or simple intensive (6), also known as semi-intensive. All trays were assembled, filled with growing substrate, planted, and top-dressed with a controlled release fertilizer (4 kg/yd^3, Osmocote Pro 22-3-8, The Scotts Company LLC, Marysville, OH) to aid establishment in the early summer of 2010 (at LiveRoof® Ontario. Only the plants which were purchased and those which were donated by Sheridan Nurseries were planted at the experimental site. Trays consisted of main species, which were the central focus for suitability testing, and minor species, which were one of four *Sedum* spp. for the full sun trial and one of three *Sedum* spp. for the partial shade trial. Each tray had between two and seven plants of the main species, depending on plant size, and varying numbers of *Sedum* plugs which were used as ground covers. The plant species used in these trays are listed in Table 1.

Species selection was based on plants having a zone hardiness of five or hardier, having a perennial life cycle, being drought tolerant, being suitable for full sun and some suitable for partial shade, and having neither extensive nor severely aggressive root systems. These principles were chosen because of the interests expressed by some in the local green roof industry.

A total of 49 trays, 40 for the full sun trial and nine for the partial shade trial, were used in this experiment. The full sun trial began on 21 Jul. 2010. Trays were arranged to form a completely randomized design and were surrounded by border trays to eliminate edge effects.

The partial shade experiment began on 1 Sept. 2010. These trays were positioned under partial shade conditions, receiving no more than approximately six hours of full sun per day, with an average of 38% of the photosynthetic photon flux that occurred under full sun conditions. Trays were placed under a 96 square foot nursery bench with a metal mesh surface. Immediately to the west of these trays was a wall which stood several meters higher than the trays and as a result the trays only received full sun for a few hours in the morning. Trays were arranged in one row with the one-foot-wide ends pushed up against each neighbouring tray. The trays were rearranged every two weeks during each growing season up until early November 2010 and until the experiment's completion in October 2011 in order to help reduce edge effects. On 13 Sept. 2010, all partial shade trays were top-dressed to aid establishment using the same fertilizer and application rate as was used for the full sun trays in order to maintain consistency.

Each main species in the full sun trial was tested separately with two minor species, whereas in the partial shade trial, each main species was tested with one minor species (Table 1).

Irrigation. All trays were irrigated by hand with city water using a garden hose. Enough water was applied at each irrigation event to wet most, if not all, of the growing substrate within a tray. Full sun trays were watered every day for the first week. During the second week, trays were watered every other day, after which they were watered only where and when necessary, based on visual water demand from plants (wilting). Partial shade trays followed the same irrigation schedule beginning from the day the main species were planted. On scheduled watering days, irrigation would only be skipped when enough rainfall was present. During the second growing season, irrigation of both trials was temporarily paused in order to imitate a period of drought to evaluate drought tolerance. Irrigation then continued as it left off in 2010 and records were kept of which trays were watered and when.

Measurements and observations. Plant measurements were taken once every two weeks until the end of the growing season in 2010 and a total of three times in 2011: once at the beginning of the growing season, once after the simulated drought, and once at the end of the season. For both full sun and partial shade trays, all plants of all main species were measured as well as three representative plants from each *Sedum* species from different trays, until the *Sedum* plants grew together and could no longer be distinguished as individuals.

Measurements included plant height and canopy diameters using the two longest, perpendicular branches, of which the latter was used to calculate canopy area.

Also, the branch number was counted for plants which had strictly tall and upright growth forms with distinct branches. Only living, major branches near the substrate surface were counted.

Finally, observations were made during irrigation events or near the same dates as the measurements, and often documented plant recovery after the simulated drought, plant failure and disease, and interactions among species.

Maintenance. For winter protection, both full sun and partial shade trays were insulated in mid-November of 2010 with pieces of rockwool. The rockwool was cut to size and used to fill gaps between the trays to help prevent root damage during the winter. Also, regular weeding was performed to reduce competition for resources and thinning was performed on aggressive plants, mostly *Sedum* spp., as necessary. *Sedum* thinning only occurred after all measurements of representative *Sedum* spp. had ceased. Finally, species adversely affected by the simulated drought were cut back either to heights of approximately four to six inches or to the tallest living node.

Results and Discussion

Suitability of species. Species were considered suitable for green roof applications in northern climates if they were able to survive over winter and if they were able to subsist through the hot and dry summers with minimal irrigation and a short establishment period. Species had to be able to endure stress, such as that caused by a drought, and be able to recover from this stress.

In the full sun trial, only *E*. *myrsinites*, *P*. *virgatum* 'Heavy Metal', *S*. *byzantina*, and *D*. *flexuosa* did not return successfully after winter (Fig. 1). Only one *D*. *flexuosa* individual survived after winter but remained fragile and vulnerable, similar to how all the *D*. *flexuosa* plants behaved shortly after installation. Based on results, these species were considered unsuitable for green roofs.

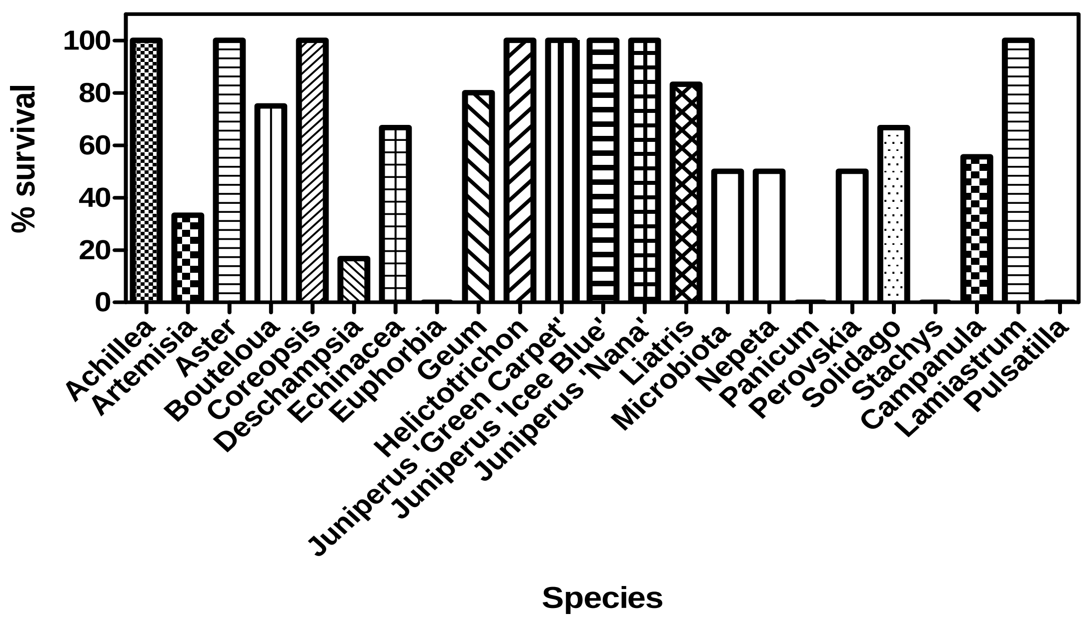

Fig. 1. Percent survival of all plants within each species. Percentage was calculated using all trays of each species and was determined at the completion of the experiment.

Late *Sedum* thinning may be to blame for the failed performance of these species. It became clear that the *Sedum* spp. were beginning growth earlier in the spring and or faster than the main species. However, there are other factors, such as failure to overwinter successfully and or possible impacts of the growing substrate conditions or harsh roof conditions that may have also been responsible. In the case of *E. myrsinites*, the cause of death appeared to be root and or stem rot which may be attributed to the prolonged wetness of the growing substrate after snow melt. All *D. flexuosa* plants appeared fragile and vulnerable from the beginning of the experiment; this species never became fully established after the trays were installed, thus placing them at more risk of being overtaken by aggressive *Sedum* spp. It would be sensible to avoid pairing any of these species with *Sedum* spp. so to prevent potential plant death, unless further green roof vegetation studies prove otherwise.

All of the remaining species in this trial were found to be suitable for green roof applications (Fig. 1), assuming the same substrate depth and irrigation methods are used. *P. atriplicifolia* 'Little Spire' was the most suitable, being able to withstand harsh conditions and requiring minimal irrigation. Other highly suitable species were *L. spicata* 'Kobold', *H. sempervirens*, *A. stelleriana* 'Silver Brocade', *S. rugosa* 'Fireworks', *N.* x*faassenii* 'Walker's Low', *B. gracilis*, *M. decussata*, *J. communis* 'Green Carpet', *J. horizontalis* 'Icee Blue', and *J. procumbens* 'Nana'. All of these species, including, *P. atriplicifolia* 'Little Spire', performed well overall, especially during the simulated drought in 2011 (Table 1).

Table 1. Plant species and species combinations: main species are listed, followed by the minor species in parentheses. Drought effects: neutral (0), for main species which appeared unaffected by the drought; negative (-), for main species which displayed stress via minor wilting; severe (- -), for main species which displayed stress via major wilting and or dead tissue; and non-applicable (N/A), for main species which did not overwinter successfully.

Full sun trial	Drought effects
Achillea millefolium 'Terra Cotta' (*S. album* 'Coral Carpet'; *S. sexangulare*)	- -
Artemisia stelleriana 'Silver Brocade' (*S. album* 'Coral Carpet'; *S. sexangulare*)	0
Aster laevis (*S. album* 'Coral Carpet'; *S. sexangulare*)	- -
Bouteloua gracilis (*S. album* 'Coral Carpet'; *S. spurium* 'Fuldaglut')	0
Coreopsis verticillata (*S. spurium* 'Dragon's Blood'; *S. spurium* 'Fuldaglut')	-
Deschampsia flexuosa (*S. album* 'Coral Carpet'; *S. spurium* 'Fuldaglut')	N/A
Echinacea purpurea (*S. spurium* 'Dragon's Blood'; *S. spurium* 'Fuldaglut')	-
Euphorbia myrsinites (*S. album* 'Coral Carpet'; *S. sexangulare*)	N/A
Geum triflorum (*S. album* 'Coral Carpet'; *S. sexangulare*)	-
Helictotrichon sempervirens (*S. sexangulare*; *S. spurium* 'Fuldaglut')	0
Juniperus communis 'Green Carpet' (*S. sexangulare*; *S. spurium* 'Dragon's Blood')	0
J. horizontalis 'Icee Blue' (*S. sexangulare*; *S. spurium* 'Dragon's Blood')	0
J. procumbens 'Nana' (*S. album* 'Coral Carpet'; *S. sexangulare*)	0
Liatris spicata 'Kobold' (*S. album* 'Coral Carpet'; *S. sexangulare*)	0
Microbiota decussata (*S. album* 'Coral Carpet'; *S. spurium* 'Fuldaglut')	0
Nepeta xfaassenii 'Walker's Low' (*S. album* 'Coral Carpet'; *S. spurium* 'Fuldaglut')	0
Panicum virgatum 'Heavy Metal' (*S. album* 'Coral Carpet'; *S. spurium* 'Fuldaglut')	N/A

Perovskia atriplicifolia 'Little Spire' (*Sedum album* 'Coral Carpet'; *S. spurium* 'Fuldaglut')	0
Solidago rugosa 'Fireworks' (*S. album* 'Coral Carpet'; *S. sexangulare*)	0
Stachys byzantina (*S. album* 'Coral Carpet'; *S. sexangulare*)	N/A
Partial shade trial	Drought effects
Campanula carpatica 'Blue Clips' (*S. sexangulare*)	0
Lamiastrum galeobdolon 'Herman's Pride' (*S. album* 'Coral Carpet')	0/-
Pulsatilla vulgaris (*S. spurium* 'Green Mantle')	N/A

Survival of *A*. *stelleriana* 'Silver Brocade' was reduced partially because of the slight fragility of the plants around the bases (substrate level), discovered during maintenance, and possibly from restrictions caused by the early growth of *Sedum* spp. In addition, survival of *N*. x*faassenii* 'Walker's Low' was reduced mostly due to insect pest disturbance and also possibly from *Sedum* spp. restrictions.

Species which were still suitable but which displayed less drought tolerance were *Achillea millefolium* 'Terra Cotta', *Aster laevis*, *Geum triflorum*, *Echinacea purpurea*, and *Coreopsis verticillata* (Table 1). Both *A. millefolium* 'Terra Cotta', which was in the early stages of flowering, and *A. laevis* were the least drought tolerant and had to be cut back after the simulated drought to remove dead material and to encourage new growth. *G*. *triflorum*, *E*. *purpurea*, and *C*. *verticillata* recovered quickly after the simulated drought and did not suffer any significant amount of damage. *G*. *triflorum* was completing its flowering phase and only one *E*. *purpurea* plant was near flowering but neither one was affected as severely as *A. millefolium* 'Terra Cotta' and *A. laevis*. Height measurements indicated the obvious height reductions of *A. millefolium* 'Terra Cotta' and *A. laevis*, due to being cut back, but did not reveal the drought sensitivities of the other species. Similarly, the calculated canopy areas only indicated the reduced canopy area of *A. laevis*. It was the total branch number that was most effective at indicating drought sensitivities.

In the partial shade trial, *P*. *vulgaris* was deemed unsuitable for green roofs. This species was extremely fragile, especially after its first winter in the trays; all plants had died before the end of June 2011. This species may not have survived possibly because of its intolerance for the growing substrate conditions or rooftop conditions, or because it lacked sufficient insulation over the winter. For instance, the growing substrate may have remained too wet for too long as the result of snow melt, thus creating unfavourable conditions for a species which prefers its substrate to be well drained (13). Also, the rockwool packed between the trays may not have provided enough insulation; having a complete border of trays like the full sun trial may have aided survival. Approximately half of these plants were performing poorly even before *Sedum spurium* 'Green Mantle' began crowding the bases of the plants in the early spring of 2011. This eliminates late *Sedum* thinning as an initial cause of their failure. Based solely on the fact that this species was unable to survive in this experiment, it is not recommended for use in green roof applications. *C*. *carpatica* 'Blue Clips' was also fragile, especially near the base of the plants, but can still be suitable as long as extra care is taken around these plants when maintenance occurs. Finally, *L*. *galeobdolon* 'Herman's Pride' was found to be the most suitable species under partial shade conditions. Although it did show a minor sensitivity to drought, it displayed a robust performance overall. *L*. *galeobdolon* 'Herman's Pride' was the only partial shade species in flower during the simulated drought.

The simulated drought revealed useful information about the true vigor of several species; some species were negatively affected while others appeared unaffected or hardly affected (Table 1). It is possible that if the severely affected *A. millefolium* 'Terra Cotta' was not flowering it may have endured the simulated drought more successfully (8). Similarly, *L*. *galeobdolon* ‘Herman’s Pride’, although less affected, may have performed even better if it too was not flowering during this period (8). To contrast with more successful species, *L*. *spicata* ‘Kobold’, *H*. *sempervirens*, *A*. *stelleriana* ‘Silver Brocade’, and *N*. x*faassenii* ‘Walker’s Low’ were all either flowering or near flowering during the simulated drought, thus suggesting that they may possess an even higher status of vigor and higher tolerance of drought, compared to the remaining species under the same conditions, as they were able to withstand drought conditions during a phase in their life cycle when plants are sometimes considered sensitive or vulnerable (8).

A. millefolium ‘Terra Cotta’ and *A. laevis* were two of the most severely affected species. A study done by Monterusso, Rowe and Rugh (9) in Michigan, just south of Ontario, also found *A. laevis* to be drought sensitive and to require supplemental irrigation when tested on an extensive green roof. Compared to the irrigation frequencies of other species, both of these species, especially *A*. *millefolium* ‘Terra Cotta’, received more irrigations prior to the simulated drought. Both species were also the most frequently irrigated over the entire duration of the 2011 growing season. This exposes their true sensitivity; *A*. *millefolium* ‘Terra Cotta’, in particular, was extra sensitive due to it being in bloom. It also emphasizes the success and suitability of the remaining species.

Appropriateness of the species for a tray system. Species that were categorized as appropriate for use in trays must have neither displayed any signs of being stressed or restricted by the trays nor caused any damage to the tray materials.

When studying the appropriateness of the main species for the tray system, excluding the species which did not survive, no restrictions were found over the duration of the experiment; plants were neither stressed nor limited by the trays. The only problem that arose pertained to the size of the aerial organs of some species, in that they grew too large, in terms of horizontal spread, thus affecting neighbouring trays by casting shade upon them. *A. stelleriana* ‘Silver Brocade’ best demonstrated this concern, thereby requiring plant thinning. In addition, the overall variation of plant heights did not present any issues either. The tallest species such as *A. laevis*, *E*. *purpurea*, *S*. *rugosa* ‘Fireworks’, and *P. atriplicifolia* ‘Little Spire’ often developed permanently leaning stems due to the windiness of the site, but were well anchored by the trays, plant roots, and growing substrate.

The tray system proved to be both useful and successful. Since all the surviving species were appropriate for the trays, it would be worthwhile to test these species in shallower systems to determine their potential for roofs with low load-bearing capacities.

Compatibilities between the main species and minor (Sedum) species. In order to be considered compatible, both species within a tray must not have negatively impacted each other and must not have shown the potential to create any negative impacts. Compatibilities were judged visually with regard to plant performances over time. *E. myrsinites*, *P. virgatum* ‘Heavy Metal’, and *S. byzantina* have been excluded from this section due to their inability to survive.

The best combination of all trays in both trials was *L. galeobdolon* ‘Herman’s Pride’ and *S*. *album* ‘Coral Carpet’. These two species presented high compatibility, possibly due in part to the fact that *S*. *album* ‘Coral Carpet’ was less aggressive in partial shade than in full sun.

Main species which displayed poor compatibility with their associated *Sedum* spp. included the fragile *P. vulgaris* and *C. carpatica* ‘Blue Clips’, which were easily over-crowded by the *Sedum* spp., as well as *D. flexuosa*, which remained small and weak throughout much of the experiment, thus making it easy for *Sedum* spp. to take over. Other poorly compatible combinations were the evergreens with *Sedum* spp. For these combinations, the *Sedum* spp. created a dense ground cover and finally grew over top of part of the lower evergreen branches, thereby shading and eventually killing part of the branches.

The only evergreen and *Sedum* combination which did not perform as poorly as the rest, was *M*. *decussata* and *S. album* 'Coral Carpet'. However, even though *M*. *decussata* formed enough shade to keep the *Sedum* in a weak state, *S*. *album* 'Coral Carpet' still made attempts to climb *M*. *decussata* in sections where it was able to access light.

In terms of abnormal plant failure, *M. decussata* plants, which were paired with *S*. *spurium* 'Fuldaglut', were slowly killed by what was studied to be likely either a fungal or bacterial blight. If not for the disease, this species combination may have performed better than most of the other evergreen and *Sedum* combinations. It may seem that this combination does not act as a good representation of the species' interactions, but since the spread of disease was gradual, the interactions were still observed. Through comparison with other trays containing the same *Sedum* species, it can be concluded that since *S*. *spurium* 'Fuldaglut' produces tall, dense canopies, it can shade out at least the lower branches of *M*. *decussata*. Although this may not kill the entire plant, it will most likely cause unnecessary plant stress and affect the aesthetics of the tray overall. Therefore to evade any risk, it is probably best to avoid pairing evergreens, such as those used in this experiment, with aggressive, ground cover *Sedum* spp.

The compatibilities of the remaining combinations were more or less mediocre. *Sedum* spp. paired well with the main species for most of the time, but extra caution was required since the *Sedum* spp. tended to crowd the bases of the main species and often made emergence difficult in spring.

Success of Sedum spp. in partial shade. Under the low lighting conditions, these *Sedum* spp. presented either aggressive behaviour (vigorous growth), or passive behaviour (weak growth).

S. album 'Coral Carpet' proved to be less aggressive and more passive in partial shade than in full sun, as mentioned earlier, and was not overly stressed by the shade. The only areas of stress occurred where the stems hung over the edges of the trays, where they became weak and easily detachable. Getter, Rowe and Cregg (7) also found *S. album* 'Coral Carpet' to be successful, in terms of creating absolute cover, however, in that experiment, this species was tested under fully shaded conditions. Although its performance may have been slightly reduced in this experiment, *S. album* 'Coral Carpet' made for a compatible combination with *L*. *galeobdolon* 'Herman's Pride'. *S*. *sexangulare*, however, was still quite aggressive. It spread quickly and did not display any strong signs of stress. It even appeared to have been less stressed than it was in full sun. Finally, *S*. *spurium* 'Green Mantle' was also still aggressive in partial shade and did not show any strong signs of stress.

Due to being ground covers, the calculated canopy areas of the *Sedum* spp. indicated more growth changes than the height measurements. In the first growing season, *S*. *sexangulare* displayed the most fluctuations in canopy area. In comparison, both *S. album* 'Coral Carpet' and *S*. *spurium* 'Green Mantle' maintained relatively constant increases in canopy area.

In this trial, the *Sedum* spp. were selected in order to test their performance under lighting conditions which simulate situations in which neighbouring buildings cast shade upon green roofs or in which *Sedum* spp. are planted beneath solar panels on green roofs. Considering and planning for all the possible mechanical structures that may be present on a roof and using optimum placement of all plant species will enhance the performance and aesthetics of the green roof as a whole.

Sedum characteristics and maintenance thinning. In terms of *Sedum* thinning, some trays were thinned before the simulated drought occurred and some were thinned afterwards; the thinning, however, did not affect the drought tolerance of the non-*Sedum* species, but certainly facilitated the emergence of some species in spring and helped initiate uncompromised plant growth. Many species, especially tall-stemmed species like *A. laevis* and *S. rugosa* 'Fireworks' performed successfully once they grew above the *Sedum* canopy, but some species can easily be lost if thinning is not completed early enough in spring to allow for uncomplicated emergence. Since, for the most part, *Sedum* spp. began growing earlier in the spring and or faster than non-*Sedum* species, they had the chance to become better established than the other species and were able to be the first to take advantage of the surrounding resources.

S. *spurium* 'Fuldaglut' and *S. spurium* 'Dragon's Blood' paired poorly with short species or those with slower growth rates because they quickly formed closed canopies with their tall stems, thus shading out everything beneath them. Similar behaviour was shown by other *S*. *spurium* cultivars, such as *S*. *spurium* 'Tricolour' and *S*. *spurium* 'Voodoo', both of which were tested on a green roof mat system (Vinson & Zheng, not published). Additionally, *S. album* 'Coral Carpet' and *S. sexangulare* paired poorly with small, short species because they crowded, climbed, tangled, and shaded due to their aggressive nature. Although not a cultivar, *S*. *album* has been found to behave the same way as *S*. *album* 'Coral Carpet', even when grown on a mat system (Vinson & Zheng, not published).

The importance of *Sedum* thinning was realized during this experiment, leading to the conclusion that many species in this genus should not be undermined and thinning should not be omitted from the maintenance to do list. It is highly recommended that thinning be performed at least twice per year if *Sedum* spp. have been planted with non-*Sedum* species. Understandably, many green roofs are designed to require minimal maintenance and or have limited or difficult access. This makes regular monitoring and plant thinning difficult in many situations. For this reason, it is of utmost importance that the proper planning goes into the selection of species being used and possibly the planting design as well.

Future research. In order to advance the findings of this experiment, future research should test the suitability of a broader range of plant species for green roofs in various climatic regions in North America. Researchers should consider selecting plant species which are familiar and perhaps popular to the general public. Also, the tray system can be tested using species with root systems which are either more extensive or more aggressive than those used in this experiment and possibly testing the long term outcomes of their growth in the trays could be done as well.

Since the *Sedum* spp. in the partial shade trial have all proven that they can thrive under the provided lighting conditions, these species should be tested in experiments involving real solar panels. This trial did not completely simulate the conditions under a solar panel since the heat that is normally emitted from a solar panel (12) was not imitated. This, therefore, creates another opportunity for future research to focus on creating a wider selection of plant species which are not only suitable for partially shaded green roof conditions, but are also heat tolerant.

Conclusion

The two settings of full sun and partial shade have allowed for a comprehensive study of plant growth and overall performance under rooftop conditions. Plant species used under either of these settings required at least some irrigation and performed best with regular monitoring and maintenance, especially since *Sedum* spp. were co-planted with each main species.

Species found to be highly suitable for green roofs in northern climates were *P*. *atriplicifolia* 'Little Spire', *L*. *spicata* 'Kobold', *H*. *sempervirens*, *A*. *stelleriana* 'Silver Brocade', *S*. *rugosa* 'Fireworks', *N*. x*faassenii* 'Walker's Low', *B*. *gracilis*, *M*. *decussata*, *J*. *communis* 'Green Carpet', *J*. *horizontalis* 'Icee Blue', and *J*. *procumbens* 'Nana' under full sun conditions and *L*. *galeobdolon* 'Herman's Pride' under partial shade conditions. The species found to be unsuitable were *E*. *myrsinites*, *P*. *virgatum* 'Heavy Metal', *S*. *byzantina*, and *D*. *flexuosa* under full sun conditions and *P*. *vulgaris* under partial shade conditions.

Also, all of the species which survived were found to be appropriate for use in the green roof tray production system.

Various compatibilities were revealed among the numerous species tested; however the most compatible species of all combinations, in both trials, were *L. galeobdolon* 'Herman's Pride' and *S*. *album* 'Coral Carpet'. In addition, the most incompatible species were *P. vulgaris*, *C. carpatica* 'Blue Clips', *D. flexuosa*, and most evergreen species, with their associated *Sedum* spp.

Finally, only *S. album* 'Coral Carpet' displayed passive behaviour under partial shade conditions, whereas both *S*. *sexangulare* and *S*. *spurium* 'Green Mantle' displayed aggressive behaviour.

References

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