RESEARCH

PLANTS INFLUENCED BY GROWING MEDIA AND COMPOST ADDITION ON MOCK GREEN ROOFS WITHIN THE OZARK HIGHLANDS

D.C. Toland,[1] M.E. Boyer,[2] G.V. McDonald,[3] C.P. West,[4] and B.E. Haggard[5]*

ABSTRACT

Green roof technology and other low impact development practices help mitigate hydrologic impacts from urbanization. Green roofs are widely recognized for stormwater retention, and these systems provide many other ecological functions, such as habitat, air quality improvements, insulation, reduced noise pollution and aesthetic quality. Green roofs are composed of a plant palette (species selected for a specific condition), growing media and drainage system on top of a traditional roof membrane.

This study investigated species survival under local environmental conditions, in the southwestern Ozark Highlands from September 2008 through 2009. There were four treatments consisting of two different growing media particle sizes and two different fertilization regimens (with and without compost). Sixteen plant species and/or varieties were monitored to determine the effect of treatments on survival and spread.

*Plant response varied by species, but the fine media with compost provided the greatest survival and spread. However, the fine media without compost treatment had similar survival rates and may provide similar cover over time. The coarse particle media treatments had greater mortality rates in most specimens and less coverage after one year. Local environmental conditions were detrimental to some species (*Sedum moranense *L.), whereas other species (*Sedum reflexum *L.;* Phedimus *sp. L.; and* Sedum spurium *L. 'Summer Glory') thrived. Our results provide valuable knowledge on creating an appropriate plant palette for green roof designs.*

KEYWORDS

green roofs, plant survivability, sustainability, media and compost mixture

[1]University of Arkansas System's Division of Agriculture, Fayetteville, Arkansas, USA.
[2]University of Arkansas, Fayetteville, Arkansas, USA.
[3]University of Arkansas System's Division of Agriculture, Fayetteville, Arkansas, USA.
[4]Texas Tech University, Lubbock, Texas, USA.
[5]Arkansas Water Resources Center, Fayetteville, Arkansas, USA. Corresponding Author: haggard@uark.edu

INTRODUCTION

Green roofs are highly regarded for their stormwater mitigation characteristics, and the available literature suggests stormwater runoff volumes may be reduced by as much as 100%. The reduction in stormwater production from green roofs has ranged from 46 to 100% depending on rainfall intensity and volume, and green roof type (Toland et al. 2014, Oberndorfer et al. 2007, DeNardo et al. 2005, Moran et al. 2005, VanWoert et al. 2005). Moreover, green roof technology and other low-impact development techniques reduced peak discharge (Bradford and Denich 2007, Carter and Butler 2008, Oberndorfer et al. 2007). Green roofs are becoming more common in the urban landscape, although adoption in the USA has been slower compared to Northern European countries. Green roof technology offers clear benefits, but its adoption in the USA has been limited by the knowledge gap about this innovative technology, as well as the length of the payback period (Hendricks and Calkins 2006).

Green roofs are designed elements that have a positive influence on many aspects of the urban environment, and Carter and Jackson (2007) recommend that these features be used as a best management practice to replicate interception and provide for evapotranspiration. Green roofs, sometimes called living roofs, are roofs covered with a lightweight growing media above a pervious drainage layer and planted with appropriate plants. There are two types of green roofs: intensive and extensive. Intensive green roofs have a growing media depth greater than 15 cm. Extensive green roofs have a growing media depth from 7.6 to 15 cm, which usually includes lightweight material and organic matter installed over a water-conducting drainage layer (Carter and Keeler 2007, Getter and Rowe 2006, Dunnett and Kingsbury 2004). Typical growing media compositions include a growing media mix of 55% expanded slate, 30% sand, and 15% organic matter (by volume) (Carter and Butler 2008, Moran et al. 2005). The organic matter is added to stimulate plant growth and establishment, and then provide nutrients over time through mineralization.

Green roof plants are usually low-growing sedums, succulents and other drought tolerant plants. In an effort to select plants to survive local environmental conditions, much research is being conducted to explore and expand the palette of plants available for extensive green roof installations to include native plant species. Some of those studies have shown that native species can be successful on extensive green roofs depending on the local climate conditions and green roof design (MacIvor et al. 2011, MacIvor and Lundholm 2011, Monterusso et al. 2005). Some plants have shown high adaptability to green roof conditions, and *Sedum* species have been shown to be more drought tolerant than forbs and grasses (Nagase and Dunnett 2010). Selected plants, such as Angelina sedum (*Sedum rupestre*), Blue Spruce sedum (*Sedum reflexum*), Six Sided sedum (*Sedum sexangulare*), several varieties of *Sedum spurium*, and several varieties of *Sedum album*, have been used in northwest Arkansas, northeast Georgia, east central Massachusetts, south central Michigan, and east central North Carolina (Carter and Keeler 2008, Moran et al. 2005, Rowe et al. 2004). Other plants have also survived green roof conditions in northwest Arkansas: chives (*Allium schoenoprasum*), fameflower (*Talium calycinum*), and *Sedum middendorffianum* (Toland et al., 2012b).

METHODOLOGY

Tests of plant performance will help determine which plants can withstand the harsh conditions in northwest Arkansas, an environment typical of the transition zone of the humid eastern U.S. ranging from eastern Oklahoma to the Carolinas. Our objective was to investigate the survival of specific plant species and varieties under the hot dry summer and below freezing winter climatic conditions of the Ozark Highlands. We compared plant growth and survival in two different size growing media, with and without compost, in mock green roofs at Fayetteville, Arkansas (36.09 N, 94.19 W). This project will help designers, contractors, nurseries, and developers select appropriate plants for extensive green roofs under similar environmental conditions.

The mock green roofs were located within the Ozark Highlands, Ecoregion 39a, Level IV (USEPA 2007). Climatic averages indicate that air temperature exceeds 32°C (90°F) for 56 days and drops below 0°C (32°F) for 105 days annually, suggesting that plants adapted to green roofs must be cold hardy and heat tolerant. Annual precipitation is 117 cm (46 in), with May and June being the wettest with over 12.7 cm (5 in) of precipitation each, and January and February the driest with less than 6.35 cm (2.5 in) on average (NOAA, 2009). The measured monthly rainfall and temperatures (low and high) are shown Figure 1, showing below freezing temperatures occurring from October 2008 to March 2009, extreme heat in July 2009 (near 38 °C), and variable precipitation across the study period. The site is at the University of Arkansas System Division of Agriculture's Watershed Research and Education Center in Fayetteville, Arkansas.

Twelve separate mock roofs (1.22 m × 1.22 m) were built to replicate typical roof construction. Roofs were constructed using pressure-treated lumber for the frame, two sheets of 2.54 cm rigid foam insulation and 1.91 cm plywood decking purchased from a local lumber company. The waterproof roofing membranes, Teranap 1M Film, were donated and installed by Siplast (Irving, TX). The down-slope side board (Figure 2) was covered with waterproof membrane Teranap 1M Sand, and was installed with a 2.54 cm gap for drainage. The twelve mock roofs were fitted with a green-roof drainage layer donated by J-DRain GRS, (JDR Enterprises Incorporated, Alpharetta, GA) immediately above the waterproofing membrane (Figure 2). This drainage layer consists of root barrier, plastic corrugated drainage material, and filter fabric and then covered with Lite-Wate Aggregate growing media donated by Chandler Materials (Tulsa, OK). Additional filter fabric material was placed around the perimeter of the drainage layer and extended up the side boards to prevent growing media from falling down in

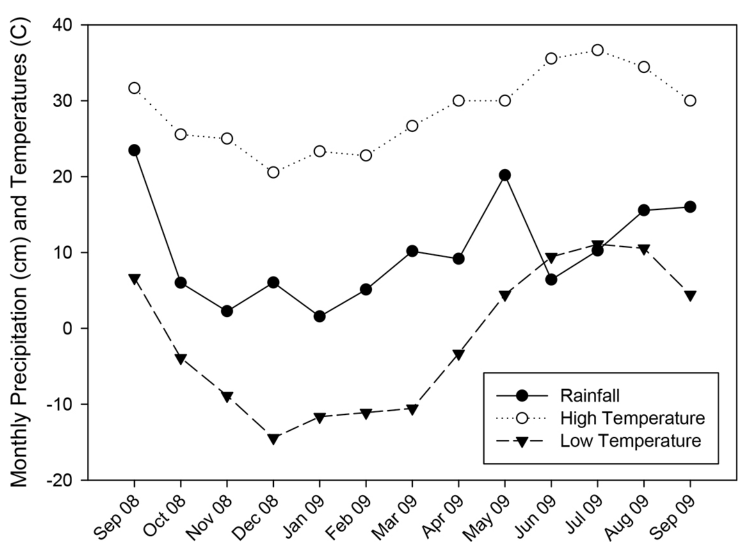
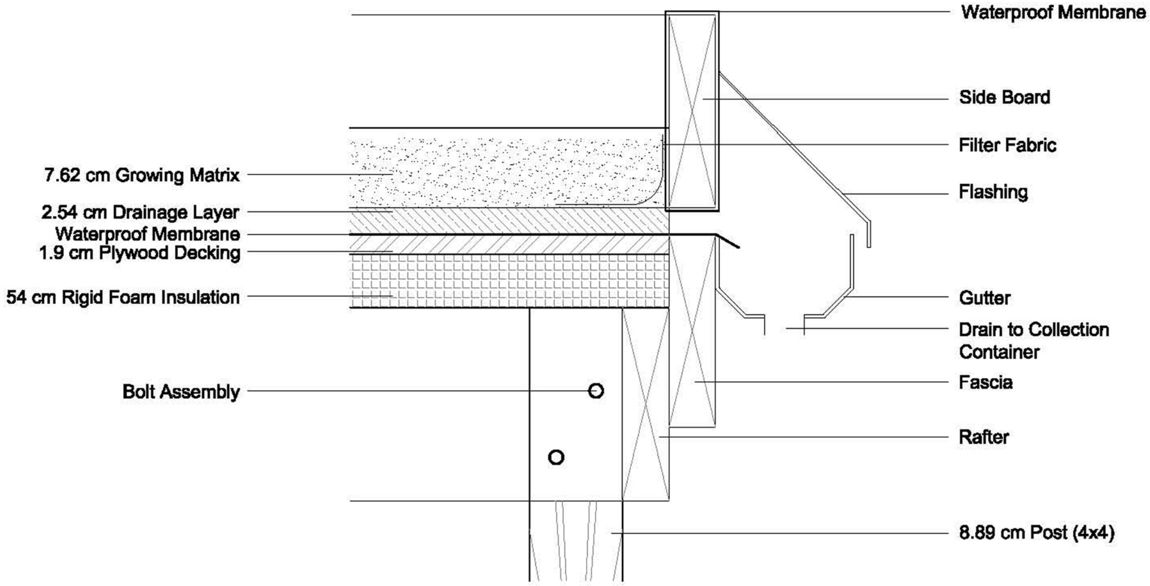


FIGURE 1. Monthly environmental data for the Fayetteville, Arkansas area including precipitation (cm), and high and low temperatures (°C) during the study period.

FIGURE 2. Cross section of a mock green roof showing matrix, drainage layer, structure, and gutter located at the Watershed Research and Education Center, Fayetteville, Arkansas.



the gap between the side board and the drainage layer. The mock green roofs were filled with a growing media, six with fine material and six with coarse (Table 1); the composition was mainly quartz and amorphous glassy structures based on x-ray diffraction. The growing media in half the roofs contained 15% (by volume) mushroom compost purchased from Nitron Industries (Fayetteville, AR) in three roofs with fine media and three with coarse media; Table 2 provides nutrient analysis of the compost and growing media. All mock green roofs were filled with growing media to a depth of 7.62 cm.

TABLE 1. General particle size information on the media used in the growing matrix of the mock green roofs (data courtesy of Chandler Materials).

	% Retained	
Sieve	Coarse	Fine
12.7 mm	0	0
9.53 mm	3	0
7.94 mm	—	0
4.75 mm	78	0
2.36 mm	15	25
1.18 mm	2	32
600 μm	0	25
300 μm	0	12
150 μm	0	4
Pan	2	2

The green roofs were built on a gravel pad to minimize any differences in sun angle and shade, spatial variance in rainfall, wind impacts, and atmospheric deposition (Table 3). Each roof was adjusted to have a 2% slope falling to the east, producing a total elevation change of 2.44 cm; the roofs were 1 m off the ground. The species/cultivars in this study were selected in part by observed plant responses to green roof conditions in a prior study at the University of Arkansas, where the plants species showed tolerance to extremes in temperature and moisture conditions (Toland et al. 2012b). Plants were donated by Emory Knoll Farm (Street, MD); were supplied as seventy-two count plugs; several new species/cultivars were suggested by this nursery. The Horticulture Department at the University of Arkansas provided the *Bouteloua dactyloides* L. as 24 count plugs. Sixteen species and/or

TABLE 2. Material analysis of growing matrix components used in mock green roofs.

	WEP	NO_3-N	NH_4-N		M3P	M3Fe	M3Al	$\%H_2O$
Material				**mg kg^{-1}**				
Coarse	0.06	<0.21	<0.21		2.13	27.6	58.5	16.1
Fine	0.19	<0.21	<0.21		3.35	46.0	96.0	17.3
					Total P %	**Total N %**	**Total C %**	
Compost	4.30	420	<0.21		0.35	0.93	9.49	64.7

Note: Abbreviations include WEP, water extractable phosphorus; NO_3-N, water extractable nitrate; $WENH_4$-N, water extractable ammonium; M3P, Mehlich 3 phosphorus; M3Fe, Mehlich 3 iron; and M3Al, Mehlich 3 aluminum

TABLE 3. Plant list for mock green roof study at the Watershed Research and Education Center in Fayetteville, Arkansas within the Ozark Highlands.

Scientific name	Common or cultivar name	Hardiness Zone
Sedum middendorffianum L. var. diffusum		5
Sedum rupestre L.	Angelina	4
Sedum reflexum L.	Blue spruce	4
Sedum sexangulare L.	Six sided sedum	4
Sedum spurium L. 'John Creech'	John Creech	5
Sedum spurium L. 'Roseum'	Roseum	4
Allium schoenoprasum	Chives	4
Talium calycinum	Fameflower	6
Phedimus sp. L.	Golden carpet	4
Sedum album L. 'Red Ice'	Red Ice	4
Sedum album L.	Jelly Bean	4
Sedum moranense L.		8
Orstachys boehmeri L.	Duncecaps	4
Sedum spurium L. 'Schorbuser Blut'	Dragons Blood	5
Sedum spurium L. 'Summer Glory'	Summer Glory	5
Bouteloua dactyloides L.	Buffalo grass	4

cultivars (Table 3) were planted in a randomized complete block design (RCBD) where each roof had four blocks of each species (Figure 3). After the initial watering at the time of planting, the only water received by the roofs came through precipitation, as these roofs were not irrigated or protected from environmental conditions.

Plants were installed September 10, 2008 and surveys were conducted on all plants to determine survivorship and spread through the first growing season after installation. Plant surveys were conducted one time each in June, July, August, September, and October 2009 to observe plant survival, growth, and recession in response to roof treatment and seasonal weather conditions. Plant spread was measured in two directions to calculate a rectangular area of coverage.

The growing media treatments were laid out as a randomized block design, where each treatment was within each one of the four blocks. Within each roof, plants were arranged in four blocks from the upslope to the downslope, where each of the 16 plants was randomly

FIGURE 3. Mock green roofs and plant layout at the Watershed Research and Education Center, Fayetteville, Arkansas within the Ozark Highlands (photo courtesy of Agricultural Communications, University of Arkansas System's Division of Agriculture).

allocated to each of four blocks (two rows of eight plants/strip, 64 plants/roof) within an individual roof. This allowed testing for a possible effect of moisture gradient from top to bottom of the slope on plant performance; these blocks are henceforth referred to as slope positions. The experimental unit is the individual plant, and the data were analyzed to determine differences in growth and survivability of the 16 species/cultivars among roof treatments and slope positions.

Survival data were analyzed in JMP 8 software (SAS Institute Inc., Cary, NC) using a contingency table, where all plants were given a designation of 0 for dead and 1 for alive. The contingency table provided data for each species percentage of survival per treatment. Statistix 9.0 (Analytical Software, Tallahassee, FL) was used to determine effects on plant spread of treatment, slope position, and time using analysis of variance (ANOVA). Comparisons were conducted on log-transformed data to minimize the influence of outliers (Hirsch et al. 1991), and log means were separated using least significant difference (LSD) at an alpha of 0.05. Species were compared to determine statistical differences in plant response between growing media particle size, and/or if there were significant differences in plant response to compost within the growing media.

FINDINGS

Plant Survival over Winter

The fine-particle media with compost (FC) had the greatest overall plant survival rate, at over 82%, followed closely by the fine-particle treatment with no compost (FN) at over 77%. Survival rates in the coarse-particle roofs were at less than 40% and substantially lower in the fine-particle treatment with and without compost.

Sedum moranense L. did not survive the winter of 2008–2009 (Table 4), indicating that this species is not cold hardy in this area under green roof conditions. This winter was exceptionally harsh for this region, and included a devastating ice storm in late January 2009. Conversely, there were three species that showed no significant difference in survival across the treatments, and two of those had high survival rates (greater than 80%) in all treatments: *Phedimus* sp. L; and *Sedum spurium* L. 'Summer Glory'. Furthermore, *Sedum reflexum* L. survived equally as well across treatments with rates of survival at or exceeding 75% (Table 4).

TABLE 4. Plant survival (% alive) on mock green roofs.

Plant	Treatment			
	CC	CN	FC	FN
Overall	**39**	**35**	**82**	**78**
Sedum middendorffianum L.*	63	37	90	90
Sedum rupestre L.*	18	28	77	63
Sedum reflexum L.	77	75	83	88
Sedum sexangulare L.*	10	8	67	92
Sedum spurium L. 'John Creech'*	73	50	100	83
Sedum spurium L. 'Roseum'*	60	63	92	95
Allium schoenoprasum *	42	12	90	88
*Talium calycinum**	40	18	78	72
Phedimus sp. L.	100	92	100	100
Sedum album L. 'Red Ice'*	0	0	83	43
Sedum album L. 'Jelly Bean'*	12	5	100	93
Sedum moranense L.	0	0	0	0
Orstachys boehmeri L.*	22	17	93	62
Sedum spurium L. 'Schorbuser Blut'*	30	53	75	87
Sedum spurium L. 'Summer Glory'	82	90	100	100
Bouteloua dactyloides L.*	0	3	87	83

*indicates differences between treatments on plant survivability Chi square $p<0.0001$.

Abbreviations include CC, Coarse media with 15% (by volume) compost added; CN, Coarse media with no compost added; FC, Fine media with 15% (by volume) compost added; and FN, Fine media with no compost added.

The remaining species showed greater survival rates in the fine-textured media (FC and FN) than those grown in the coarse-textured media (CC and CN), although there were differences in the responses. *Sedum middendorffianum* L., *Sedum spurium* L. 'Roseum', *Allium schoenoprasum* L., *Sedum album* L. 'Jelly Bean', and *Bouteloua dactyloides* L. all had similar survival rates (within 10%) between the fine media with or without compost (Table 4). *Sedum rupestre* L., *Talium calycinum* L., *Sedum album* L. 'Red Ice', and *Orostachys boehmeri* L. showed a preference for the fine media with compost (FC) compared to the fine media without compost (FN). *Sedum spurium* L. 'John Creech' also showed a 10% greater survivability between fine treatments (FC and FN), but the fine without compost (FN) was only 10% greater than the coarse media with compost (CC). Whereas, *Sedum sexangulare* L. and *Sedum spurium* L. 'Schorbuser Blut' showed a 10% greater response to fine without compost media (FN) compared to fine with compost media (FC) (Table 4).

When comparing species survivability within the coarse media (CC and CN), *Sedum spurium* L. 'Schorbuser Blut' was the only species where the coarse media without compost (CN) had a survival rate 10% greater than the coarse media with compost (CC). Four species, including *Sedum middendorffianum* L., *Sedum spurium* L. 'John Creech', *Allium schoenoprasum* L., and *Talium calycinum* L., had 10% greater survivability on the coarse media with compost green roofs (CC) (Table 4). All remaining species showed survival rates on the coarse media roofs with and without compost within 10% of each other.

Plant Spread across Treatments

Several similar responses among to treatments with respect to plant spread occurred among species (Table 5). *Sedum middendorffianum* L., *Allium schoenoprasum* L., and *Sedum album* L. 'Jelly Bean' all had the greatest spread in the fine particle media with compost (FC), followed by the fine particle media without compost (FN), then coarse particle media with compost (CC), and finally the coarse particle media without compost treatment (CN).

The species showed greatest spread on fine particle media with compost (FC), followed by the fine media without compost (FN), and the least spread observed was on the coarse-particle media regardless of presence of compost (CC and CN). The species showing this response included *Sedum rupestre* L., *Sedum album* L. 'Red Ice', *Orstachys boehmeri* L., *Sedum spurium* L. 'Summer Glory', and *Bouteloua dactyloides* L. (Table 5).

A third response was that plant spread was greatest in the fine-particle media with or without compost (FC and FN) compared to that observed in the coarse-particle media (CC and CN) (Table 5). The plants showing this spread pattern included *Sedum spurium* L. 'Roseum', *Talium calycinum* L., and *Sedum spurium* L. 'Schorbuser Blut'. The growth by species in the coarse media varied across these particular species. Similarly, *Sedum sexangulare* L. showed the least growth in the coarse media with and without compost (CC and CN); however, the greatest plant spread appeared in the fine media without compost (FN), instead of the fine media with compost (FC). *Sedum reflexum* L. did not exhibit a difference in spread within the fine media (FC and FN), and there was also no significant difference in spread between the fine media with or without compost (FC and FN) and coarse media with compost (CC).

There were two species that did not follow the aforementioned responses but instead showed a stronger response to nutrient supply from the compost (Table 5). *Sedum spurium* L. 'John Creech' showed the greatest spread on the fine media with compost (FC) roofs, followed by fine media without compost (FN) and then coarse media with compost (CC), and the least spread was in the coarse media without compost (CN). The greatest response of spread to compost presence was observed in *Phedimus* sp. L. where the spread was greatest on the green roofs with compost (CC and FC). This species had the next greatest spread in the fine media without compost (FN), which was significantly greater than the coarse media without compost (CN).

Slope Position Effects

The slope position effect was not highly variable within each species; however, there were significant differences within species and several trends arose. The first observed trend was that some plants had greater spread at the bottom of the slope (location 4) compared to the same species at the top of the slope (location 1), including *Sedum middendorffianum* L., *Allium schoenoprasum* L., *Sedum album* L. 'Red Ice', and *Sedum spurium* L. 'Schorbuser Blut' (Table 6). *Allium schoenoprasum* and *Sedum album* L. 'Red Ice' actually grew well across locations with the exception of location 1 (top of slope). Two other plants showed a greater spread near the bottom of the slope (location 3), *Sedum spurium* L. 'John Creech' and *Sedum spurium* L. 'Roseum'.

The second trend between plant spread and location was that no significant difference existed across slope position. *Sedum sexangulare* L., *Talium calycinum* L., and *Orstachys boehmeri* L. showed no significant difference in plant spread across the slope positions of the mock green roofs (Table 6).

TABLE 5. Mean plant spread in square centimeters by treatment on mock green roofs.

	Treatment (cm^2)			
Plant	**CC**	**CN**	**FC**	**FN**
Sedum middendorffianum L.*	C	D	A	B
	1.73	0.10	30.0	8.58
Sedum rupestre L.	C	C	A	B
	0.04	0.07	3.86	1.04
Sedum reflexum L.	AB	B	A	A
	5.53	2.94	14.9	15.5
Sedum sexangulare L.	C	C	B	A
	0.01	0.02	2.10	5.16
Sedum spurium L. 'John Creech'	B	C	A	B
	3.35	0.28	99.5	5.31
Sedum spurium L. 'Roseum'	B	B	A	A
	2.41	1.31	74.4	35.2
Allium schoenoprasum	C	D	A	B
	0.07	0.02	3.39	0.87
Talium calycinum	B	C	A	A
	0.09	0.02	1.01	0.61
Phedimus sp. L.	A	C	A	B
	262	22.2	384	73.0
Sedum album L. 'Red Ice'	C	C	A	B
	0.01	0.01	22.0	0.17
Sedum album L. 'Jelly Bean'	C	D	A	B
	0.02	0.01	196	18.2
Sedum moranense L.	—	—	—	—
	0	0	0	0
Orstachys boehmeri L.	C	C	A	B
	0.03	0.02	4.76	0.53
Sedum spurium L. 'Schorbuser Blut'	C	B	A	A
	0.07	0.30	7.10	7.85
Sedum spurium L. 'Summer Glory'	C	C	A	B
	14.4	9.03	156	73.7
Bouteloua dactyloides L.	C	C	A	B
	0.01	0.01	7.03	2.33

*Plant spreads across rows with the same letter were not significantly different with LSD at an alpha of 0.05.

Note: Abbreviations include CC, coarse media with 15% (by volume) compost added; CN, coarse media with no compost added; FC, fine media with 15% (by volume) compost added; and FN, fine media with no compost added.

A few plants showed distinct and surprising patterns across slope position. One species, *Bouteloua dactyloides* L., was the only species which showed a greater spread at the top of the slope (location 1) compared to the other locations. *Sedum spurium* L., 'Summer Glory', was also unique in that it did well in the two middle rows. All other plants showed no definite response to location within the green roof locations (Table 6).

TABLE 6. Mean plant spread in square centimeters by slope position within mock green roofs, where position 1 was at the top of the slope and position 4 was at the bottom.

	Slope position (cm^2)			
Plant	**1**	**2**	**3**	**4**
Sedum middendorffianum L.*	B	AB	A	A
	1.36	2.03	3.67	4.39
Sedum rupestre L.	AB	A	B	AB
	0.27	0.65	0.19	0.37
Sedum reflexum L.	A	AB	B	AB
	13.9	9.39	3.60	8.00
Sedum sexangulare L.	A	A	A	A
	0.23	0.20	0.34	0.18
Sedum spurium L. 'John Creech'	B	B	A	B
	3.74	4.44	13.1	2.29
Sedum spurium L. 'Roseum'	B	B	A	B
	7.77	7.69	49.4	2.83
Allium schoenoprasum	B	A	A	A
	0.10	0.41	0.32	0.27
Talium calycinum	A	A	A	A
	0.19	0.21	0.19	0.18
Phedimus sp. L.	A	A	B	A
	138	145	70.8	114
Sedum album L. 'Red Ice'	B	A	A	A
	0.06	0.16	0.16	0.24
Sedum album L. 'Jelly Bean'	AB	B	A	B
	1.09	0.82	1.63	0.75
Sedum moranense L.	0	0	0	0
Orstachys boehmeri L.	A	A	A	A
	0.16	0.25	0.15	0.25
Sedum spurium L. 'Schorbuser Blut'	B	B	AB	A
	0.63	0.67	1.04	2.83
Sedum spurium L. 'Summer Glory'	C	A	AB	BC
	16.9	64.1	47	29.1
Bouteloua dactyloides L.	A	B	B	B
	0.79	0.34	0.35	0.20

*Values within a row with the same letter were not significantly different with LSD at an alpha of 0.05.

Plant Spread over Growing Season

Plant growth and desiccation were observed across the first growing season with several trends standing out (Table 7). All species except *Talium calycinum, Phedimus* sp. L., and *Bouteloua dactyloides* L. experienced a decline in spread after the first measurement. *Talium calycinum* and *Bouteloua dactyloides* L. exhibited little to no change in spread across time and *Phedimus*

TABLE 7. Mean plant spread in square centimeters by sampling date on mock green roofs during the 2009 growing season, June through October.

	Sampling Date (cm^2)				
Plant	**June**	**July**	**Aug**	**Sept**	**Oct**
Sedum middendorffianum L.*	A	B	C	C	C
	37.3	6.23	0.84	0.82	0.73
Sedum rupestre L.	A	B	C	C	C
	3.82	0.91	0.14	0.11	0.07
Sedum reflexum L.	A	AB	BC	C	C
	35.2	15.8	5.53	3.82	2.48
Sedum sexangulare L.	A	AB	BC	C	C
	1.38	0.30	0.12	0.11	0.11
Sedum spurium L. 'John Creech'	A	B	C	C	C
	50.4	16.1	1.5	1.39	1.38
Sedum spurium L. 'Roseum'	A	AB	BC	C	BC
	35.5	15.3	6.8	4.85	4.44
Allium schoenoprasum	A	B	B	B	B
	0.90	0.21	0.20	0.17	0.13
Talium calycinum	A	A	A	A	B
	0.23	0.23	0.22	0.32	0.07
Phedimus sp. L.	C	C	BC	AB	A
	75.9	90.0	110	141	174
Sedum album L. 'Red Ice'	A	AB	B	B	AB
	0.27	0.18	0.10	0.10	0.11
Sedum album L. 'Jelly Bean'	A	A	A	A	A
	1.48	1.28	0.78	0.73	1.04
Sedum moranense L.	—	—	—	—	—
	0	0	0	0	0
Orstachys boehmeri L.	A	B	C	C	C
	3.00	0.63	0.06	0.06	0.04
Sedum spurium L. 'Schorbuser Blut'	A	A	B	B	B
	8.67	3.46	0.39	0.34	0.32
Sedum spurium L. 'Summer Glory'	A	AB	B	AB	AB
	60.9	44.3	22.6	27.9	30.3
Bouteloua dactyloides L.	A	A	A	A	A
	0.30	0.32	0.30	0.41	0.61

*Values within a row with the same letter were not significantly different with LSD at an alpha of 0.05.

sp. L. was the only plant to show increasing spread over the growing season (Table 7). Three plants, *Sedum album* L. 'Jelly Bean', *Sedum spurium* L., 'Summer Glory', and *Bouteloua dactyloides* L. began to show an increase in spread at the October measurement after a decline in measurements in July, August and September.

DISCUSSION

The different size growing media influenced plant survival and spread over the growing season, which was likely due to differences in water retention following rainfall events. The fine media retained 20% more rainfall annually compared to the coarse media, and the greatest seasonal retention occurred when plants were actively growing (data shown in Toland et al. 2013). Over half the plants evaluated in this study had better survival and/or growth on the fine media, probably resulting from increased water availability post-rainfall events. The fine media also remained moist longer after rainfall events, based on visual observations in the current study. Moran et al. (2005) reported that *Sedum reflexum*, *Sedum album*, and *Sedum sexangulare* had a substantial amount of spread in central and eastern North Carolina, where these plants were grown in a media similar to the coarse media, but with 30% sand and 15% organic matter incorporated; it is likely the sand increased the water retention of the coarse media, promoting plant growth. VanWoert et al. (2005) also observed similar response in plant growth for a coarse media with sand, which may explain why there was a lesser response by the species on coarse media in the current study. The addition of compost to coarse media promotes increased plant coverage over time owing to nutrient release; Toland et al. (2012b) showed coarse media with added compost had significantly higher coverage than fine media without added compost over two years after establishment.

Based on this study, the recommended plant species for green roofs in northwest Arkansas and other places within the Ozark Highlands ecoregion and the US Department of Agriculture defined Hardiness Zone 6b would include the following. Species that did relatively well across all treatments include *Sedum reflexum* 'Blue Spruce', *Phedimus sp*., and *Sedum spurium* 'Summer Glory'. Species that should be considered only for a fine-particle size media include *Sedum middendorffianum*, *Sedum rupestre*, *Sedum sexangulare*, *Allium schoenoprasum*, *Talium calycinum*, *Sedum album* 'Jelly Bean', *Sedum spurium* 'Schorbuser Blut', and *Bouteloua dactyloides.* Species that would be suitable for green roofs with coarse-particle size media include *Sedum spurium* 'John Creech' and *Sedum spurium* 'Roseum'. Species that would not be recommended for green roofs in this ecoregion include *Sedum album* 'Red Ice' (or fine media with compost only applications), *Sedum moranense,* and *Orstachys boehmeri.*

These recommendations should be considered when designing the plant palette along with other information in the literature on plant survival, growth and effects on green roof systems. Other plants that have survived on green roofs systems and that would be recommended for this region included *Sedum kamtschaticum* (if compost was used in the growing media) and *Delosperma ecklonis* var. *latifolia* (Toland et al. 2012b). Sutton et al. (2012) showed that many prairie and grassland species like *Bouteloua dactyloides* survived and thrived on green roofs, and these types of plants deserve further evaluation in the Ozark Highlands beyond this study.

The industry has been using organic matter additions to the growing matrix in green roofs to promote plant survival and growth, and several plants expressed a secondary response to the compost added in the current study. However, recent research has shown that nutrients (nitrogen, N, phosphorus, P, and total organic carbon, TOC) from the added compost are released into stormwater during rainfall events (Monterusso et al. 2004, Berndtsson et al. 2006, Hathaway et al. 2008, Toland et al. 2014). Nutrient concentrations and loads are much greater than those from green roofs without added compost, and even from conventional roofs with little water retention capacity. Nutrient loss was greatest in the first six months for the green roofs used in this study, except for P which remained elevated throughout the first year (Toland et al. 2014). Toland et al. (2012a) sampled runoff waters from established green roofs, showing that runoff total N and P concentrations were still elevated two years later. Various types of fertilizer and compost and levels of addition have been evaluated in green roof trials, and those studies that monitored runoff nutrient loss reported increases relative to green roofs without added nutrients to the growing media. Nagase and Dunnett (2011) observed that 10% organic matter was sufficient to promote plant growth, which was the least amount added in their study. Future studies need to focus on a balance between the use of organic matter and or fertilizers to promote plant survival and growth and the potential nutrient losses in stormwater over longer duration.

This study evaluated a range of plant species on the mock green roof systems, whereas other studies have looked at individual plant species per roof. The amount of runoff, which influences nutrient transport, changes with plant types, where grasses are the most effective at retaining water followed by forbs and then sedums (Nagase and Dunnett 2012). This study only focused on one grass, *Bouteloua dactyloides* L. (Buffalo grass), which showed some promise for use on green roofs in this climactic region. The variation in plant spread across the growing season suggests that a plant palette consisting of early and late growth might enhance the hydrologic benefits provided by green roofs. The variation in plant spread across slope position suggests that there may be moisture implications to roofs with slopes as low as two percent even in free draining green roof systems. The next series of experiments needs to consider how individual plants and or diverse mixes of plant species might influence water retention in this and other regions, similar to the Ozark Highlands, USA.

CONCLUSIONS

The results of this study provided evidence on how 16 plant species would perform on mock green roofs in the Ozark Highlands. Some of those 16 species of plants appear to be suitable candidates for green roofs in this climatic zone and one species (*Sedum moranense* L.) is not suited for green roofs in this climatic zone. All species except one (*Bouteloua dactyloides* L.) showed increased winter survival in a fine-particle media, and all species exhibited higher vegetative spread in a fine-particle media.

Variety in the plant palette will foster greater biodiversity in the green roof system, which will promote biodiversity as a whole. When selecting plant species, other data within this study may be beneficial to inform a more complementary planting plan. For example, some species emerge early but growth dwindles in later season. These early growth species should be planted with species that will maintain or spread later in the growing season. The combination of these species promotes green roof coverage across the growing season, thereby increasing biodiversity and seasonal interest, especially on green roofs that are visible. Plants are not only an important part of the green roof functionally through stormwater interception and evapotranspiration, but these plants also create scenery, wildlife habitat, and an overall healthy environment.

Future studies should investigate if there is a lesser compost volume or other fertilizing alternative that would provide an acceptable level of plant growth and survival in comparison to what was seen in this study. Although with proper planning, increased nutrients in green roof runoff can be mitigated by using other green hydrologic features, such as rain gardens, bioswales, etc.

REFERENCED WORK

Berndtsson, J.C., T. Emilsson, and L. Bengtsson. (2006) 'The influence of extensive vegetated roofs on runoff water quality', *Science of the Total Environment*, Vol 355, pp 48-63.

Bradford, A., and C. Denich. (2007) 'Rainwater management to mitigate the effects of development on the urban hydrologic cycle', *Journal of Green Building*. Vol 2, pp 37-52.

Carter, T., and C. Butler. (2008) 'Ecological impacts of replacing traditional roofs with green roofs in two urban areas', *Cities and Environment,* Vol 1, Article 9.

Carter, T., and C.R. Jackson. (2007) 'Vegetated roofs for stormwater management at multiple scales' *Landscape and Urban Planning*, Vol 80, pp 84-94.

Carter, T., and A. Keeler. (2008) 'Life-cycle cost-benefit analysis of extensive vegetated roof systems', *Journal of Environmental Management*, Vol 87, pp 350-363.

DeNardo, J.C., A.R., Jarrett, H.B. Manbeck, J.D. Beattie, and R.D. Berghage. (2005) 'Stormwater mitigation and surface temperature reduction by green roofs', *Transactions of the American Society of Agricultural and Biological Engineers,* Vol 48, pp 1491-1496.

Dunnett, N., and N. Kingsbury. (2004) 'Planting green roofs and living walls', Timber Press, Inc. Portland, OR.

Getter, K.L., and D.B. Rowe. (2006) 'The role of extensive green roofs in sustainable development', *HortScience,* Vol 41, pp. 1276-1285.

Hathaway, A.M., W.F. Hunt, and G.D. Jennings. (2008) 'A field study of green roof hydrologic and water quality performance', *Transactions of the American Society of Agricultural and Biological Engineers,* Vol 51, pp. 37-44.

Hendricks J.S., and M. Calkins. (2006) 'The adoption of an innovation: barriers to use of green roofs experienced by Midwest architects and building owners', *Journal of Green Building*, Vol 1, pp. 148-168.

MacIvor, J.S and J.T. Lundholm. (2011) 'Performance evaluation of native plants suited to extensive green roof conditions in a maritime climate', *Ecological Engineering,* 37, 407-417.

MacIvor, J.S., M.A. Ranalli and J.T. Lundholm. (2011) 'Performance of dryland and wetland plant species on extensive green roofs', *Annals of Botany,* 107, 671-679.

Monterusso, M.A., D.B. Rowe, and C.L. Rugh. (2005) 'Establishment and persistence of *Sedum* spp. And native taza for green roof applications', *HortScience,* 40(2):391-396.

Monterusso, M.A., D.B. Rowe, C.L. Rugh, and D.K. Russell. (2004) 'Runoff water quantity and quality from green roof systems', *Acta Horticulture,* Vol 639, pp. 369-376.

Moran, A., B. Hunt, and J. Smith. (2005) 'Hydrologic and water quality performance form green roofs in Goldsboro and Raleigh, North Carolina'. Proceedings of the 3rd North American Green Roof Conference: Greening rooftops for sustainable communities, Washington, DC. The Cardinal Group Toronto. pp. 512-525.

Nagase, A., and N. Dunnett. (2010) 'Drought tolerance in different vegetation types for extensive green roofs: effect of water and diversity', *Landscape and Urban Planning*, Vol 97, pp. 318-327.

Nagase, A., and N. Dunnett. (2011) 'The relationship between percentage of organic matter in substrate and plant growth in extensive green roofs', *Landscape and Urban Planning*, Vol 103, pp. 230-236.

Nagase, A., and N. Dunnett. (2012) 'Amount of water runoff from different vegetation types on extensive green roofs: effects of plant species, diversity and plant structure', *Landscape and Urban Planning*, Vol 104, pp. 356-363.

NOAA. (2009) Washington County, Arkansas Climatology Including Fayetteville, National Oceanic and Aeronautics Administration. WFO Tulsa, OK. National Weather Service Tulsa, OK. Available online at http://www.srh.noaa.gov/tsa/?n=climo#d (Accessed April 29, 2010)

Oberndorfer, E., J. Lundholm, B. Bass, R.R. Coffman, H. Doshi, N. Dunnett, S. Gaffin, M. Kohler, K.K. Liu, and D.B. Rowe. (2007) 'Green roofs as urban ecosystems: ecological structures, functions, and services', *Bioscience*, Vol 57, pp. 823-833.

Rowe, D.B., C.L. Rugh, and D.K. Russell. (2004) 'Runoff water quantity and quality from green roof systems', *Acta Horticulture*, Vol 639, pp. 369-376.

Sutton, R.K., J.A. Harrington, L. Skabelund, P. MacDonagh, R.R. Coffman, and G. Koch. (2012) 'Prairie-based green roofs: literature, templates and analogs', *Journal of Green Building*, Vol 7, pp. 143-172.

Toland, D.C., M.E. Boyer, and B.E. Haggard. (2014) 'Stormwater nutrient loss from green roofs with added compost greatest in first several months, remains elevated for phosphorus', *Transactions American Society of Agricultural and Biological Engineers* (Submitted, December 2013).

Toland, D.C., B.E. Haggard, and M.E. Boyer. (2012a) 'Evaluation of nutrient concentrations in runoff water from green roofs, conventional roofs, and urban streams', *Transactions American Society of Agricultural and Biological Engineers*, Vol 55, pp. 99-106.

Toland, D.C., C.P. West, and M.E. Boyer. (2012b) 'Media composition influences green roof plant viability in the Ozark Highlands', *Journal of Green Building*, Vol 7, pp. 73-84.

USEPA. (2007) Level III Ecoregions of the Continental United States. National Health and Environmental Effects Research Laboratory.U.S. Environmental Protection Agency Document (Map). U.S. EPA Washington, D.C. Available online at www.epa.gov/wed/pages/ecoregions.htm. (Accessed May 29, 2010).

VanWoert, N.D., D.B. Rowe, J.A. Andersen, C.L. Rugh, R.T. Fernandez, and L. Xiao. (2005) 'Green roof stormwater retention: effects of roof surface, slope, and media depth', *Journal of Environmental Quality*, Vol 34, pp. 1036-1044.

ACKNOWLEDGEMENTS

The funding for the construction of the mock green roofs at the Watershed Research and Education Center was provided by the Women's Giving Circle associated with the University of Arkansas. Many of the materials used in this study were donated by the companies listed in the methods, including Chandler Materials, J Drain and Siplast (listed in alphabetical order), and the plants were donated by Emory Knolls Farms and the Horticulture Department, University of Arkansas. The graduate research assistantship was supported by the Arkansas Water Resources Center and the Crop, Soil and Environmental Sciences Department through the Agricultural Experiment Station.