Comparison of Organic and Synthetic Fertilizers for Sedum Green Roof Maintenance[1]

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Abstract

Fertility is an important aspect of green roof maintenance. Aesthetic quality and growth of two sedum species (*Sedum album* and *Sedum rupestre* 'Angelina') treated with synthetic granular fertilizer [Green View 10N-4.4P-8.3K (10-10-10)] and two organic fertilizers [Coast of Maine 4N-0.9P-1.7K (4-2-2) and Nature Safe 8N-2.2P-4.5K (8-5-5)] at 10 g N·m^{-2} applied as a single spring application or a split application (spring and summer) and a controlled-release fertilizer [Nutricote 14N-6.1P-11.6K (14-14-14)] at the same rate and a no fertilizer control were evaluated. The best aesthetic quality and growth was for the single application synthetic granular fertilizer, followed by the split application of synthetic granular fertilizer. Also, single applications were better than split application for the organic fertilizers, indicating that sedums use nutrients the most in spring. The organic fertilizers performed poorly because they failed to provide utilizable nutrients in adequate quantities. A low level of microbial activity in green roof media, may have contributed to the minimal amount of utilizable nutrients released by the organic fertilizers. Plants treated with controlled-release fertilizer performed similarly to the control, however, the following spring they had the best aesthetic quality, indicating the prills contained some residual nutrients.

Index words: Coast of Maine™, Green View®, Nature Safe®, Nutricote®, controlled-release, pour-through, saturated media extract, leachate.

Species used in this study: *Sedum album*, *Sedum rupestre* 'Angelina'.

Significance to the Nursery Industry

This study has significance for green industry companies involved in fertility management of green roofs. Based on the findings from this work we recommend a single spring application of a balanced synthetic granular fertilizer at the rate of 8–10 g N·m^{-2}. This rate will maintain green roof aesthetics while minimizing cost and producing acceptable nutrient runoff. For long-term coverage, a combination of spring application of synthetic granular fertilizer with a long duration (180 day) thermoplastic resin-based controlled-release fertilizer may be useful. Specific knowledge of nutrient release from organic fertilizers is necessary when developing a fertility plan incorporating organic fertilizers. Application of organic fertilizers at an equivalent rate of nitrogen to a synthetic granular fertilizer will not produce similar results as synthetic granular fertilizer due to differences in nutrient availability.

Introduction

The desire for extensive green roofs is rapidly increasing due to their environmental benefits including storm water management, energy conservation, urban heat island mitigation, noise reduction, extension of roof life, and habitat creation (13). Green roof business has increased by 35% every year since 2007, according to one LiveRoof® licensed Connecticut green roof grower (5). In 2011, the green roof industry in North America increased by 115% (1). Several states in the United States offer tax incentives for implementing green roofs (20) and in Toronto, Canada, the construction of green roofs is required on new development (4).

Extensive green roofs consist of less than 15 cm of substrate (20) composed of mostly (75–90%) inorganic materials such as expanded slate, clay or shale, perlite, or scoria that do not break down rapidly over time (6). The remainder of the substrate is composed of organic matter such as peat, bark or compost. *Sedum* plants are often grown on extensive green roofs because they tolerate shallow substrates and adverse rooftop conditions of drought, high heat, direct sunlight, wind and snow load (13). Extensive green roofs may be sown directly on the roof using plugs, cuttings, seed or vegetated mats or installed using vegetated modules (20).

There is little published information available about fertility management on established green roofs for maintaining plant health, and it is unclear to what degree these recommendations are based on scientific fertility studies. German green roof guidelines recommend an annual application of controlled-release fertilizer at the rate of 5 g N·m^{-2} (12). Rowe et al. (19) found that the application of controlled-release fertilizer at a rate of 6.5 g N·m^{-2} per year is necessary to maintain plant health with typical green roof substrates. The LiveRoof® Maintenance Protocol (3) suggests a controlled-release granular fertilizer that provides 4 to 6 months of continuous feeding, if fertilizer is recommended following an annual fertility test. Information about organic fertilizers for maintaining plant health on extensive green roofs is completely lacking. Green roofs are utilized to promote sustainable building practices and use of organic fertilizers for managing fertility could be a desirable maintenance option. The objective of this study was to evaluate the ability of organic and synthetic fertilizers to maintain sedum on green roofs.

Materials and Methods

This study was initiated in 2010 and completed in 2012. In 2010, experimental units were established with vegetation, and in 2011, synthetic and organic fertilizers were evaluated for their ability to maintain plant health. The 2010 growing

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season may be considered the production year and the 2011 growing season may be considered the first maintenance year. The experimental unit for this study was a 4.88 liter round container filled with LiveRoof® (LiveRoof LLC, Spring Lake, MI) green roof medium to a depth of 10 cm (3.9 in). On May 25, 2010, 30 g of *Sedum* cuttings were distributed on the media surface of each container. Two species of *Sedum*, *album* and *rupestre* 'Angelina', were used and each container received 15 g of cuttings of each species. Cutting length ranged from 3 to 8 cm (1.2 to 3.1 in). In total, 100 containers were sown, and immediately following sowing containers were covered with 47% shade fabric for approximately 21 days. During this time, containers were irrigated daily using overhead sprinklers with each container receiving approximately 380 ml of water. On June 15, 2010, the shade fabric was removed and each container was top-dressed with 8 g of OsmocotePlus® (Scotts Co., Marysville, OH) 15N–3.9P–10K (15-9-12) controlled-release fertilizer 3- to 4-month formulation. At this time the irrigation was changed to every other day, with each container receiving approximately 380 ml of water at each irrigation event, and this continued until October 10, 2010. By the end of the 2010 growing season container surfaces were 95% vegetated with *Sedum*. In nursery production, green roof units or modules are considered ready for sale when 95% or more of the surface of the media is covered with vegetation and vegetation coverage is determined by visual observation (personal communication, LiveRoof Licensed Grower). On October 10, 2010, containers were moved to a minimally heated overwintering house where they remained until April 6, 2011, when they were moved to an outdoor container nursery with gravel base and spaced 46 cm (18.1 in) on center.

In 2011, we evaluated two organic fertilizers, Coast of Maine™ (OCM) [Coast of Maine Organic Products, Portland, ME] 4N-0.9P-1.7K (4-2-2) and Nature Safe® (ONS) [Griffin Industries LLC, Cold Spring, KY] 8N-2.2P-4.5K (8-5-5), one synthetic granular fertilizer, Green View® (SGV) [Lebanon Seaboard Corp., Lebanon, PA.] 10N-4.4P-8.3K (10-10-10), and one synthetic controlled-release fertilizer, Nutricote® (SNT) [Sun Gro Horticulture Ltd., Canada] 14N-6.1P-11.6K (14-14-14). The fertilizers were selected based on their similarity of nutrient (N-P-K) composition. The fertilizers have differences in their N formulations, both in form and proportion of the total N analysis (Table 1). All fertilizers were top-dressed within each container at rates that yielded 0.5 g of N per container. In addition, for the organic fertilizers and the synthetic granular fertilizer, we evaluated the same seasonal rate of 0.5 g N per container, but split into two applications of 0.25 g N each. Single applications and first split applications occurred on May 2, 2011. The second split application occurred on June 27, 2011. Also included in this study was a no fertilizer control, making the total number of treatments, eight. Experimental units were arranged as a randomized complete block design with 12 replications (96 containers total). Containers received natural precipitation.

In 2011, the number of inflorescences was counted on June 6 and the width of vegetation was measured on June 27 (week 8) and August 29 (week 16). Width of vegetation was measured twice, at right angles to each measurement, and averaged. Experimental units were visually rated for aesthetic quality based on foliage color. Desirable, nutrient rich foliage is green for *S. album* and yellow for *S. rupestre* 'Angelina', while less desirable, nutrient poor foliage is red for *S. album* and orange for *S. rupestre* 'Angelina'. Experimental units were evaluated visually using a rating scale of 1 to 7 where 1 = less than 15% green and yellow, 2 = 15 to 30% green and yellow, 3 = 31 to 45% green and yellow, 4 = 46 to 60% green and yellow, 5 = 61 to 75% green and yellow, 6 = 76 to 90% green and yellow and 7 = greater than 90% green and yellow. Pots were rated weekly in 2011 starting on the third week (week 3 of the study) following the first fertilizer application until week 12, and then again during week 14 and week 16.

Pour-through nutrient extraction analysis was conducted on May 1, 2011, one day prior to the first fertilizer application, again two weeks after first fertilizer application, and then at three week increments until August 29, 2011, when a destructive harvest of half of the experimental replications began. Three replications were subjected to pour-through analysis and the same three replications were always tested. Pour-through extraction procedures according to Wright (23) were used with some modifications. A volume of 200 ml distilled water was used to displace the leachate. Leachate was collected and delivered to the University of Connecticut Soil Testing Facility (Storrs, CT) for analysis of pH and soluble salts (electrical conductivity). Destructive harvest of half of the experimental blocks (48 containers total) began on August 29, 2011, and lasted three days. For the harvest, all aboveground vegetation was removed, dried at 70C (158F) for 5 days and then weighed. For four replications, samples of dried tissue were sent to the University of Connecticut Soil Testing Facility for analysis of ammonium and phosphorous.

The remaining 6 replications (48 pots) were overwintered in place but containers were positioned in a closely staggered arrangement. During the 2012 growing season containers were re-spaced and received natural precipitation. On June 6, 2012, the number of inflorescences was counted. On August 6, 2012, the remaining containers were destructively harvested as described above and dry weight was recorded. Data for number of inflorescences, width of vegetation, dry weight and foliar nutrient content were subjected to analysis

Table 1. N-P-K analysis and nitrogen formulation of the fertilizers used.

Abbreviation	Fertilizer[z]	N-P-K analysis	Nitrogen source
OCM	Coast of Maine 4-2-2	4-0.9-1.7	Poultry manure (4%)
ONS	Nature Safe 8-5-5	8-2.2-4.5	NH_4-N (0.3%); water insoluble meat meal (6.8%); water soluble bone and blood meals (0.9%)
SGV	Green View 10-10-10	10-4.4-8.3	NH_4-N (10%)
SNT	Nutricote 14-14-14	14-6.1-11.6	NH_4-N (7%); NO_3-N (7%)

[z]Origin: Coast of Maine from the Coast of Maine Organic Products, Portland, ME; Green View from Lebanon Seaboard Corp., Lebanon, PA; Nature Safe from Griffin Industries LLC, Cold Spring, KY; Nutricote from Sun Gro Horticulture Ltd., Canada.

of variance (PROC MIXED) and mean separation using Fisher's least significant difference test ($P \leq 0.05$) using SAS for Windows Version 9.2 (SAS Institute Inc.).

We evaluated nutrient release from the fertilizers used in the 2011 container study (Table 1) using two different procedures, Saturated Media Extraction (SME) and leaching. Fertilizers were incorporated into LiveRoof medium to supply N at 0.1 $g \cdot dm^{-3}$ and each treatment was prepared in triplicate. Samples of each treatment replication were immediately extracted using the SME procedure (21) to evaluate nutrient release by accumulation in the medium. Bulk samples were stored in sealed plastic bags at 20C (68F). Moisture content of the bulk samples was adjusted to approximately 20% by weight. After 7, 14 and 21 days of incubation, SME extracts were obtained from aliquots approximately 250 cm^3. To evaluate nutrient release and leaching potential, samples of each treatment replication were transferred to plastic pots 12 cm tall with a volume of 465 cm^3. Pots were filled to the brim with LiveRoof medium then tapped lightly to settle the medium and create about 5 mm freeboard for irrigation. Pots were placed in a holder that allowed free drainage into a 500 ml beaker placed beneath each pot. The medium was initially wetted up by application of deionized water, in 50 ml increments, until leaching was observed. This leachate was collected and pooled with subsequent leachate. The next day, and at intervals of 7, 14 and 21 days thereafter, the medium in each pot was leached with 250 ml deionized water applied in 50 ml increments with a precision dispenser. The volume of leachate was estimated gravimetrically. Leachate and SME extracts were refrigerated prior to analysis, which occurred during the same week they were obtained. Standard colorimetric procedures were used to measure ammonium, nitrate and phosphate (9, 11, 17).

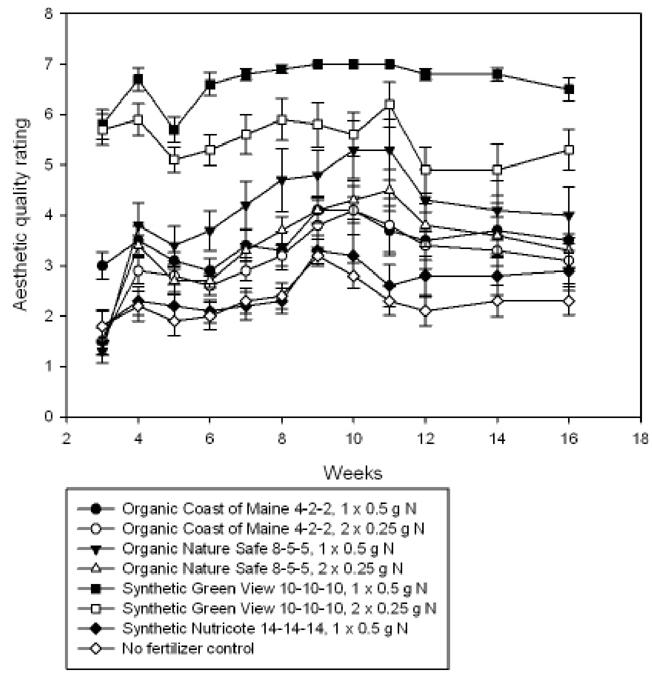

Fig. 1. Aesthetic quality ratings in 2011 for two sedum species grown using green roof medium and treated with a single or split applications of synthetic granular fertilizer and two organic fertilizers, a controlled-release fertilizer and no fertilizer control. Ratings were based on foliage color where green and yellow is most desirable and red and orange is least desirable as follows: 1 = less than 15% green and yellow, 2 = 15 to 30% green and yellow, 3 = 31 to 45% green and yellow, 4 = 46 to 60% green and yellow, 5 = 61 to 75% green and yellow, 6 = 76 to 90% green and yellow and 7 = greater than 90% green and yellow. Vertical bars indicate ± 1 SE.

Results and Discussion

Throughout the 2011 growing season single application SGV treatment had the greatest aesthetic quality (Fig. 1). The second greatest aesthetic quality was observed for split application SGV and the third greatest aesthetic quality was observed for single application ONS. The split application ONS and OCM treatments performed similarly and had greater aesthetic quality than the no fertilizer control. Both SGV treatments achieved peak aesthetic quality sooner and maintained this level of quality for longer than all organic treatments. The single application SGV achieved an aesthetic quality rating of nearly 7, which was the highest aesthetic quality rating possible, at every evaluation after week 5 of the study. Aesthetic quality for split application SGV declined by approximately one whole rating point between week 11 and 12 of the study and then leveled off despite the second split application of fertilizer, which occurred at week 9. Similarly, for ONS treatments aesthetic quality declined between week 11 and 12 and then leveled off. Aesthetic quality for SNT was not significantly different from the no fertilizer control.

In 2011, the single application SGV produced the most inflorescences at 49, and was significantly greater than the split application organic treatments and the no fertilizer control, which produced approximately 36 inflorescences (Table 2). Vegetation width at week 8 of the study was greater for the single application SGV than all other treatments (Table 2). Vegetation width at week 16 of the study was greatest for both SGV treatments, and lowest for the split application organic treatments, SNT and the no fertilizer control. Vegetation width was intermediate for the single application organic treatments at both week 8 and 16. In 2011, foliar dry weight was approximately two times greater for both SGV treatments than it was for all other treatments, which did not differ from each other significantly (Table 2). Foliar nitrogen content was greatest for split application SGV and lowest for SNT and the no fertilizer control (Table 2). Foliar nitrogen content was intermediate for the organic treatments, but ONS treatments were slightly greater than OCM treatments. The split application SGV had greater foliar phosphorous content than the single application SGV, SNT, split application ONS, and the no fertilizer control (Table 2). Foliar phosphorous content of the OCM treatments and the single application ONS did not differ significantly from all other treatments.

In 2012, the SNT produced a greater number of inflorescences than all other treatments (Table 2). The SNT produced 10 times more inflorescences as the no fertilizer control and 3 to 4 times more inflorescences than all other treatments. The number of inflorescences produced by the single application SGV was greater than the no fertilizer control. Number of inflorescences for split application SGV and the organic treatments was not significantly different from the no fertilizer control. Foliar dry weight in 2012 was greatest for SNT and lowest for the no fertilizer control (Table 2). Foliar dry weight was similar for the SGV and ONS treatments and they were intermediate compared to all other treatments. The OCM treatments had low foliar dry weight and split

Table 2. **Number of flowers, width of vegetation, species dry weight and foliar nutrient content for seven fertilizer treatments and the no fertilizer control collected in 2011 and 2012.**

Fertilizer treatment	No. inflorescences	Width of vegetation[z] June 27 (week 8)	Width of vegetation[z] Aug. 29 (week 16)	Foliar dry weight (g)	Foliar nutrient content (%) Nitrogen	Foliar nutrient content (%) Phosphorous
2011	(n = 12)	(n = 12)	(n = 12)	(n = 6)	(n = 4)	(n = 4)
Organic Coast of Maine 4-2-2, 1× 0.5 g N	42.9ab[y]	17.2bcd	18.1bc	24.5b	0.89cd	0.39ab
Organic Coast of Maine 4-2-2, 2× 0.25 g N	36.9b	16.4cd	17.1cd	26.1b	0.87cd	0.41ab
Organic Nature Safe 8-5-5, 1× 0.5 g N	39.9ab	17.3bc	18.6b	22.3b	1.06b	0.38ab
Organic Nature Safe 8-5-5, 2× 0.25 g N	35.6b	16.2d	17.0cd	22.8b	1.00bc	0.42b
Synthetic Green View 10-10-10, 1× 0.5 g N	49.0a	19.7a	21.2a	46.2a	0.95bcd	0.32b
Synthetic Green View 10-10-10, 2× 0.25 g N	40.5ab	18.0b	20.6a	43.9a	1.24a	0.46a
Synthetic Nutricote 14-14-14	44.3ab	16.6cd	17.3cd	21.6b	0.84de	0.34b
No fertilizer control	36.2b	16.2d	16.5d	18.4b	0.72e	0.35b
2012	(n = 6)			(n = 6)		
Organic Coast of Maine 4-2-2, 1× 0.5 g N	2.3bc	—	—	18.6cd	—	—
Organic Coast of Maine 4-2-2, 2× 0.25 g N	2.2bc	—	—	14.7de	—	—
Organic Nature Safe 8-5-5, 1× 0.5 g N	2.8bc	—	—	19.2bc	—	—
Organic Nature Safe 8-5-5, 2× 0.25 g N	3.0bc	—	—	19.4bc	—	—
Synthetic Green View 10-10-10, 1× 0.5 g N	3.8b	—	—	23.1b	—	—
Synthetic Green View 10-10-10, 2× 0.25 g N	2.0bc	—	—	21.9bc	—	—
Synthetic Nutricote 14-14-14	10.0a	—	—	28.0a	—	—
No fertilizer control	0.8c	—	—	13.3e	—	—

[z]Width of vegetation was measured twice, at right angles to each measurement, and averaged.

[y]Mean separation within columns, within year, indicated by different letters, by Fisher's least significant difference test ($P \leq 0.05$).

application OCM was not significantly different from the no fertilizer control.

Results of the pour-through analysis showed that at two weeks after the first fertilizer application timing, the single application SGV had the greatest electrical conductivity (EC) at 650 uS·cm^{-1} (Fig. 2). The split application SGV, had the second highest EC at 400 uS·cm^{-1}, and, as expected, this value was halfway between those for single application SGV and the no fertilizer control. The single application ONS had higher EC at 300 uS·cm^{-1}, than the remaining treatments, which had EC of approximately 200 uS·cm^{-1}. All treatments had EC values of approximately 200 uS·cm^{-1} by week 5 of the study, and for all treatments except the split application SGV and the split application ONS, EC remained at this level until week 12 and then started to decline. As expected, at week 11, two weeks after the second split fertilizer application, EC for split application SGV increased to 400 uS·cm^{-1}. During this time, EC increased to approximately 250 uS·cm^{-1} for split application ONS. There were no significant changes in pH over the course of the study for all treatments (data not shown).

In the leaching study, SGV had EC of approximately 1500 uS·cm^{-1} at day 7 and 750 uS·cm^{-1} at day 14, and these values were greater than all other treatments (Fig. 3A). EC declined to approximately 350 uS·cm^{-1} by day 21 and 200 uS·cm^{-1} by day 28. EC on day 7 of the study approximated 600 uS·cm^{-1} for ONS, 400 uS·cm^{-1} OCM for and 240 uS·cm^{-1} for SNT and the no fertilizer control, and EC for these treatments gradually declined to approximately 200 uS·cm^{-1} by day 28. The SGV on day 7 of the study had greater ammonium-N and phosphate-P concentrations, at 12 mg·liter^{-1} and 4 mg·liter^{-1}, respectively, than the other treatments (Fig. 3B and 3C). Ammonium-N and phosphate-P declined rapidly between days 7 and 14 of the study. By day 28 of the study SGV had 0 mg·liter^{-1} ammonium-N and 0.5 mg·liter^{-1} phosphate-P. Ammonium-N and phosphate-P concentration was negligible for the ONS, SNT and the no fertilizer control throughout the study. OCM had slightly less than 2 mg·liter^{-1} of ammonium-N at day 7 of the study, and this level declined to 0 mg·liter^{-1} by day 21 (Fig. 3B). OCM maintained 0.5 mg·liter^{-1} of phosphate-P throughout the study (Fig. 3C).

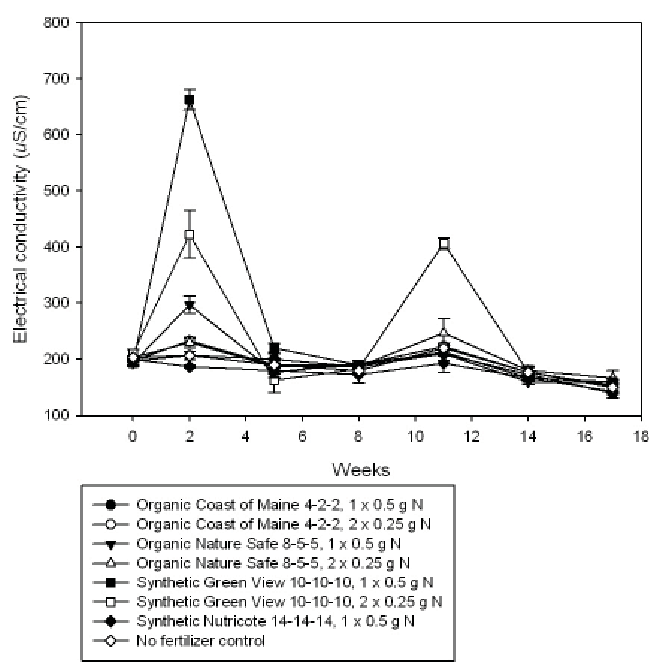

Fig. 2. **Electrical conductivity values from pour-through analysis for two sedum species grown using green roof medium and treated with a single or split applications of synthetic granular fertilizer and two organic fertilizers, a controlled-release fertilizer and no fertilizer control. Vertical bars indicate ± 1 SE.**

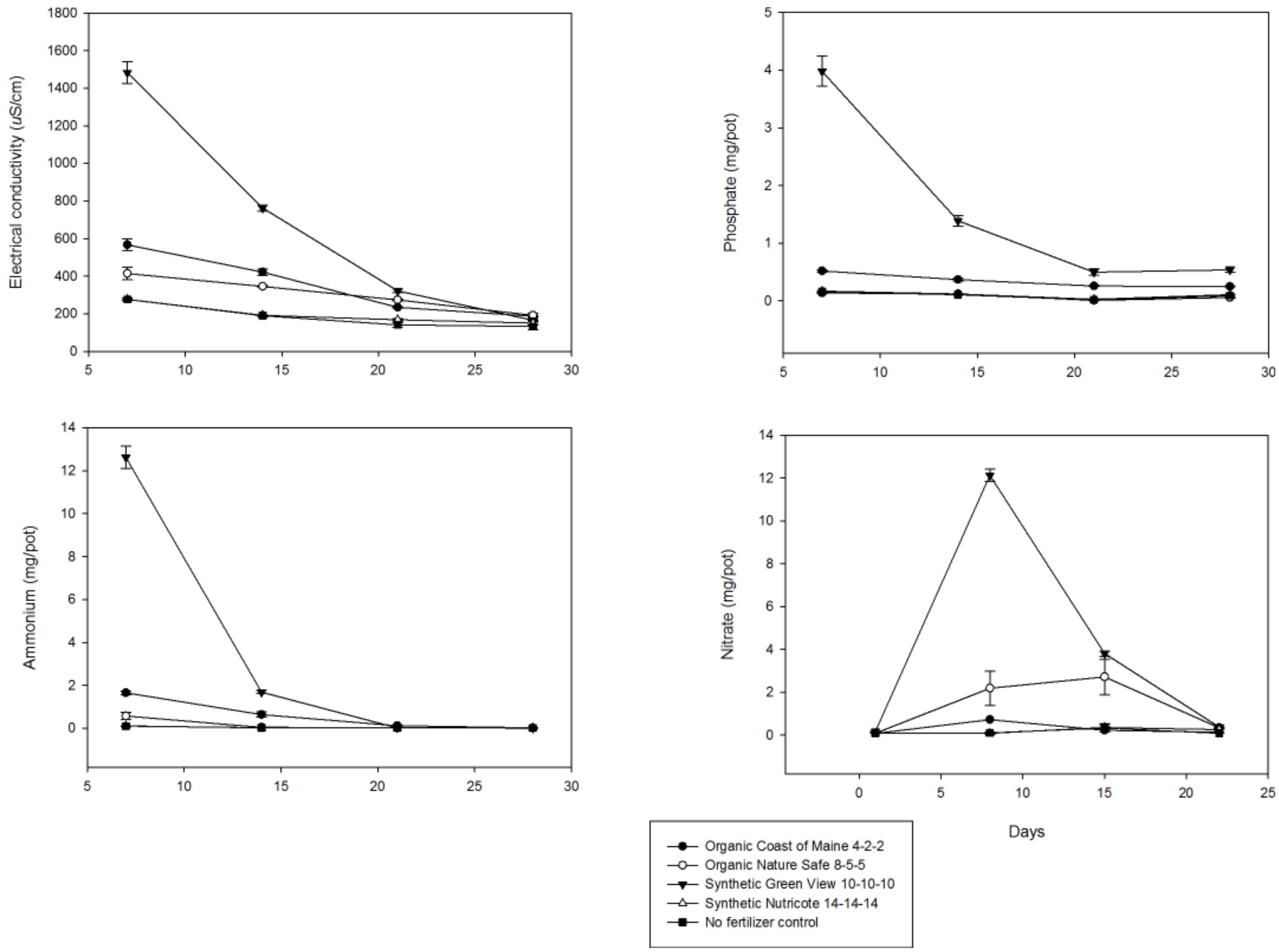

Fig 3. Leaching rates of nitrate, phosphate, ammonium and electrical conductivity from green roof medium treated with a synthetic granular fertilizer, two organic fertilizers, a controlled-release fertilizer or no fertilizer. Data points are the means of three replications. Vertical bars indicate ± 1 SE.

Nitrate-N for SGV increased rapidly to 12 mg·liter^{-1} by day 8 of the study, and then declined to 0 mg·liter^{-1} by day 22 (Fig. 3D). Conversely, nitrate-N concentration for ONS increased gradually to only approximately 3 mg·liter^{-1} by day 15, and then declined to 0 mg·liter^{-1} by day 22. Nitrate-N concentration was negligible for OCM, SNT and the no fertilizer control. There was no significant change in pH for the leaching or the saturated media extraction studies for all treatments (data not shown).

At all SME, SGV had the greatest EC and SNT and the no fertilizer control had the lowest (Fig. 4A). EC for SGV had reached approximately 2100 uS·cm^{-1} by day 7 of the study, and then leveled off. EC for both organic treatments reached approximately 1000 uS·cm^{-1} by day 14 of the study, and between days 14 and 21, ONS remained at 1000 uS·cm^{-1} and OCM declined to approximately 850 uS·cm^{-1}. EC for SNT and the no fertilizer control increased slightly from approximately 250 to 400 uS·cm^{-1} over the course of the study.

At the start of the SME experiment (day 0) the concentration of ammonium-N for SGV was approximately 45 mg·liter^{-1} (Fig. 4B). This was eight times greater than the next highest treatment, which was OCM at 5 mg·liter^{-1}. Ammonium-N for SGV declined uniformly over the course of the study to 0 mg·liter^{-1} by day 21. Ammonium-N for OCM treatment declined to 0 mg·liter^{-1} by day 14 of the study. ONS showed an increase in ammonium-N to 15 mg·liter^{-1} by day 14 of the study and then it declined to 0 mg·liter^{-1} by day 21. Ammonium-N was 0 mg·liter^{-1} for SNT and the no fertilizer control at all SME.

Phosphate-P from SME for SGV was approximately 20 mg·liter^{-1} at day 0 and significantly greater than the other treatments (Fig. 4C). Between days 0 and 7, phosphate-P for SGV declined rapidly, and by day 14 the concentration was 4 mg·liter^{-1}, and it remained at this level until day 21. Phosphate-P for OCM was approximately 5 mg·liter^{-1} at day 0. By day 7 it had declined to 2 mg·liter^{-1} and remained at this level until day 21. Phosphate-P was negligible for ONS, SNT and the no fertilizer control.

Nitrate-N from SME was greatest for SGV followed by ONS (Fig. 4D). OCM had greater nitrate-N than SNT and the no fertilizer control at days 14 and 21. Nitrate-N for SGV reached approximately 85 mg·liter^{-1} by day 7 of the study, and declined to approximately 75 mg·liter^{-1} by day 21. Compared to SGV, the increase in nitrate-N for the organic treatments was slower and maximum values were reached at day 14 of the study. The maximum nitrate-N for ONS was approximately twice that for OCM. Nitrate-N concentration for OCM declined to approximately 20 mg·liter^{-1} by day 21

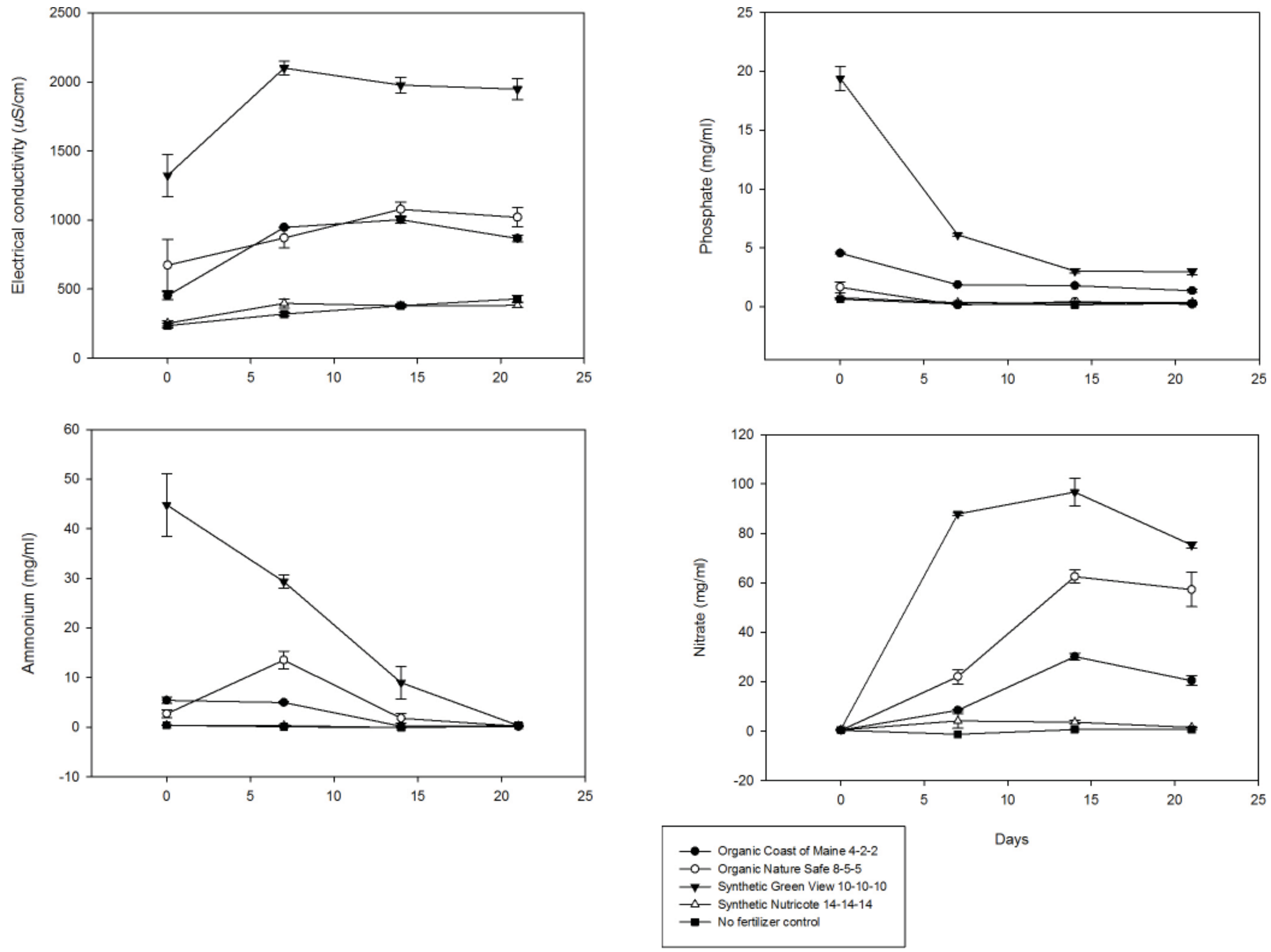

Fig 4. Saturated Media Extract values for nitrate, phosphate, ammonium and electrical conductivity from green roof medium treated with a synthetic granular fertilizer, two organic fertilizers, a controlled-release fertilizer or no fertilizer. Data points are the means of three replications. Vertical bars indicate ± 1 SE.

of the study. Nitrate-N accumulation was negligible for SNT and the no fertilizer control.

The synthetic granular fertilizer, SGV, produced better aesthetic quality foliage and more growth than the organic fertilizers, ONS and OCM, and the synthetic controlled-release fertilizer, SNT. While ONS was slightly better than OCM at producing desirable foliage aesthetics, both organic fertilizers performed poorly overall because they did not provide nutrients in a form that could be utilized by sedum roots. Organic fertilizers require soil microbes to convert nutrient sources to utilizable compounds that can be absorbed by plant roots (16). The growing medium used on green roofs, and in this study, is largely inorganic and the level of microbial activity is probably lower than common garden soils or nursery container media. A low level of microbial activity may have contributed to the minimal amount of utilizable nutrients released by the organic fertilizers in this study.

The controlled release fertilizer used in this study, SNT, provided even less usable nutrients than the organic fertilizers and this may be partially attributed to the long duration formulation (180 days) of this product. Another possible reason could be the Nutricote prill, which is composed of thermoplastic resins that are highly impermeable to water (14), which make the prills highly resistant to fluctuations in media temperature (8, 15, 22). Cabrera (8) evaluated seven different controlled-release fertilizers including Nutricote and found that Nutricote and one other fertilizer with similar prill technology exhibited the greatest temperature stability. Cabrera's (8) findings also demonstrated that thermoplastic resins released less nitrogen and soluble salts than all other controlled-release fertilizers tested. In another study, plants supplied Nutricote controlled-release fertilizer did not perform as well as plants supplied a controlled-release fertilizer using different prill release technology (22).

A single spring application of SGV resulted in better aesthetic quality and plant performance than split applications of SGV, and the same was found for each of the organic fertilizers. These findings indicate that sedums utilize nutrients at the onset of growth in early spring and the splitting of fertilizer into two applications is not advantageous. Cabrera (8) pointed out the importance of matching plant developmental stage with nutrient availability when preparing a fertility plan. In the wild, sedums are typically found occupying dry, well-drained sites that receive significant water from rain or melting snow in early spring. Mineral nutrients that have built up in the soil over the dry period are mobilized in spring and taken up by plant roots. Once nutrients are depleted from the soil by plant uptake or leaching, sedums remain relatively inactive for the remainder of the growing season. Sedums in this study did not respond favorably to split applications of nutrients where half of the fertilizer was supplied during the summer, because they are not actively growing at this time.

We suggest a single spring application of a balanced synthetic granular fertilizer as part of an annual maintenance plan to achieve vibrantly colored, high performance sedum green roofs. The rate used in this study was approximately 10 g $N \cdot m^{-2}$, and it is possible lower rates could be used to produce similar sedum aesthetic quality. Some investigators do not recommend the use of granular fertilizers because of the potential for high initial nutrient concentrations in runoff, especially in cases where the rooftop was recently planted (3, 12). German green roofing guidelines recommend the rate of 5 g $N \cdot m^{-2}$ using a controlled-release fertilizer (12). The desirable range for EC for green roof media is 400–800 $uS \cdot cm^{-1}$ based on saturated media extract analysis (2). For the single application SGV in our study, maximum EC from pour-through analysis was 650 $uS \cdot cm^{-1}$ (Fig. 2). Cavins et al. (10) showed that EC values derived from pour-through analysis are 1.4 to 1.6 times higher than EC values derived from saturated media extract analysis. The maximum EC we measured for the single application SGV is well within the desirable range for green roofs.

Compared to synthetic, granular fertilizers, controlled-release fertilizers provide a constant rate of nutrients over the course of the growing season and are therefore considered by some to be a safer option as far as nutrient leaching is concerned (3, 12). However controlled-release fertilizers may not provide an adequate amount of nutrients in early spring when sedums benefit from nutrients the most. Cabrera (8) found that controlled-release fertilizers, whose release pattern is based on differences in prill coating thickness, did not supply nutrients at a constant rate over a seven-month period and had greater nutrient release during the warmest months. It is uncertain whether controlled-release fertilizers of this type would benefit sedums and storm water quality over a synthetic, granular fertilizer applied at an appropriate rate on established green roofs. Sedum green roofs may benefit from the combination of a spring application of synthetic granular fertilizer and a controlled-release fertilizer composed of prills with release technology similar to Nutricote. In this study, plants treated with Nutricote had improved flower display (Table 2) and foliage color the following spring probably because the Nutricote prills contained some residual nutrients.

This study and research by Prasad et al. (18) demonstrate that specific knowledge of nutrient release from organic fertilizers is necessary when developing a fertility plan, since using an equivalent amount of nitrogen to a synthetic, granular fertilizer will not produce similar results. Increasing the application rate of organic fertilizers to compensate for their lack of readily utilizable nutrients may be effective at improving sedum green roof aesthetics, however there may be associated risks as far as nutrients in runoff. Nutrient content of runoff may be of particular concern if using organic products composed largely of poultry manure, which has been found to produce dangerous levels of phosphorous in leachate (7). We observed slightly elevated levels of utilizable phosphorous produced at a fairly constant rate for the poultry manure based fertilizer in this study, indicating the potential for nutrient leaching over the long term.

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