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Fertilizer rate influences production scheduling of sedum-vegetated green roof mats

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ABSTRACT

To investigate the influence of controlled-release fertilizer application rates on summer-propagated sedum-vegetated green roof mat production timing, unfertilized sedum-vegetated mats (control) were compared to mats fertilized in August 2011 with Nutricote® Total 18–6–8 100 day controlled-release fertilizer at 5, 10, 15, 20, 25, and 35 g m^{-2} N. Fertilization rate influenced vegetative coverage, shoot height, inflorescence height and canopy area, leaf greenness and weed biomass. Mat production was completed late fall, following fertilization at ≥25 g m^{-2} N, while production was completed early the next spring, following fertilization at <25 g m^{-2} N. Although vegetative coverage of individual *Sedum* spp. changed over the course of the study, acceptable overall vegetative coverage was maintained following fertilization at ≥25 g m^{-2} N throughout the 2012 growing season. Production time ranged from 63 to 300 days following fertilization at 25 g m^{-2} N and the control, respectively. Fertilization rate influenced inflorescence characteristics of *Sedum* spp. and maximum leaf greenness was calculated to occur after fertilization with 25.6 g m^{-2} N. Therefore, by adjusting controlled-release fertilizer rates, production of green roof mats can be accelerated or slowed to meet production scheduling timelines.

1. Introduction

The area of installed North American green roofs has been increasing annually, with over one million more square feet of green roofs installed in 2012 than 2011 (Green Roofs for Healthy Cities, 2013). In 2012, 1.3 million square feet of green roofs were installed in the Washington DC metropolitan region alone (Green Roofs for Healthy Cities, 2013) with the main purpose of increasing building energy efficiency and increasing ecological functions in the urban environment (Getter et al., 2011; Oberndorfer et al., 2007). The high demand for green roof plants continues to provide opportunities for the horticultural industry to meet these needs. Extensive green roofs (i.e., sedum-vegetated green roof systems grown in ≤15 cm growing substrate; FLL, 2008) are most commonly installed (Green Roofs for Healthy Cities, 2013). *Sedum* spp. are used on green roofs because they can grow in shallow substrates (Durhman et al., 2007; Emilsson, 2008) and unfavorable environmental conditions (Durhman et al., 2006; Getter and Rowe, 2006; Wolf and Lundholm, 2008). Cuttings of some *Sedum* spp. shoots are often used to propagate green roof mats or applied in direct-to-roof plantings for multiple green roof systems in temperate climates. Between 12 and 18 months are often needed from cutting application to complete vegetation coverage on green roofs (Snodgrass and Snodgrass, 2006). The time needed to produce green roof systems (i.e., mats) in the nursery varies, and production completion is based on vegetative coverage (e.g., proportion coverage ≥0.8; FLL, 2008). Decreasing the time taken to produce marketable, cutting-propagated, sedum-vegetated green roof mats could help growers meet industry demands. Therefore, efficient production strategies are needed for sedum-vegetated green roof systems.

Sedum-vegetated green roof mats are commonly propagated in the spring; however, green roof installations in temperate climates are possible late into the fall. If production space becomes available late summer, growers may have the opportunity for late-summer propagated green roof mat production. Propagating and fertilizing *Sedum* spp. late summer can be considered unconventional, as slowing *Sedum* spp. growth can occur due to a transition from vegetative to reproductive growth or environmental stresses.

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However, previous research has indicated summer-propagation of sedum-vegetated green roof systems can be successful following appropriate fertilization (Clark and Zheng, 2014b).

Previous research has demonstrated that growing substrate fertility levels influence vegetative coverage, plant growth, and visual appeal of green roof systems (Clark and Zheng, 2012, 2013, 2014a,b; Emilsson et al., 2007; FLL, 2008; Retzlaff et al., 2009). Fertilizer-influenced *Sedum* spp. growth and vegetative coverage have decreased green roof module production timing in previous studies (Barker and Lubell, 2012; Clark and Zheng, 2014b). Production timing is primarily based on vegetative coverage, and is therefore, an important parameter to consider when adapting a green roof production fertilization plan.

Overall, to meet the industry demand for green roof plants, efficient green roof plant production, fertility programs and production scheduling need to be developed for individual climate regions. The objective of this study was to identify optimum controlled-release fertilizer application rates for summer-propagated sedum-vegetated green roof mats in the temperate North American climate.

2. Materials and methods

Field soil was graded to a slight slope in order to facilitate drainage at the green roof mat production site (Sedum Master, Princeton, ON; lat. 43°11′34″N, long. 80°35′56″W) on 21 July 2011. Three 1 m × 9 m replicate plot rows were installed, arranged as seven 1 m × 1 m fertilizer treatment plots per row and one additional border plot installed at each row end. A 1 m-wide unplanted strip was left between each row to provide access to the plots. Overall, 21 treatment plots were installed in a randomized complete block design with each row representing one block.

Plots were constructed in the following manner: a thin black plastic sheet was positioned on the ground under the plots for weed suppression, under a clear vapor barrier (6 mil Vapour Barrier; Polytarp Products, Toronto, ON) below a black plastic tangle mat (Bright Green Roofing and Living Walls LLC, Detroit, MI), which was topped with 2.5 cm of Sedum Master's standard green roof growing substrate. The substrate was comprised of 83% inorganic (i.e., sand, crushed brick) and 17% organic material (i.e., peat, compost, and coir), with 5.8% air-filled porosity, 0.81 g cm^{-3} dry bulk density, 62% volumetric water content, electrical conductivity (EC) of 4493 μS cm^{-1} and pH of 7.93. The substrate, subsampled at installation, contained 830 mg kg^{-1} total nitrogen (N), 810 mg kg^{-1} total phosphorus (P) and 2200 mg kg^{-1} total potassium (K). Total Kjeldahl N was determined using a classical Kjeldahl digestion and a Skalar segmented flow autoanalyzer, and NO_2^- and NO_3^- were determined using ion chromatography by SGS Agri-Food Laboratories, Guelph, ON. Both P and K were analyzed using a borate fusion-internal standard and X-ray fluorescence spectrometry method by SGS Laboratories, Lakefield, ON. The plant-available nutrient composition of the substrate was 283 mg kg^{-1} NO_3^-, 2.67 mg kg^{-1} P, and 263 mg kg^{-1} K (analyzed using a saturated paste extraction method by SGS Agri-Food Laboratories, Guelph, ON). Wooden dividers measuring 1 m × 2.5 cm × 2.5 cm were installed between plots to ensure plot separation. Cuttings of the following *Sedum* spp., with an average length of approximately 4 cm, were spread evenly by hand on top of the growing substrate at the standard commercial rate of 10.5 g · m^{-2}: *S. acre* L., *S. hybridum* L. 'Czar's Gold', *S. kamtschaticum* Fisch., *S. kamtschaticum* subsp. *ellacombeanum* (Praeger) R.T. Clausen, *S. rupestre* L. 'Blue Spruce', *S. rupestre* L. 'Angelina', *S. selskianum* Regel & Maack 'Goldilocks', *S. sexangulare* L., *S. spurium* M. Bieb., *S. spurium* M. Bieb. 'Dragon's Blood' and *S. spurium* M. Bieb. 'Tricolor'. After two weeks (5 Aug. 2011), additional cuttings were spread evenly on the plots to replace cuttings washed away during a strong rain storm. Following standard production practices, irrigation water (pH 8.0 ± 0.4; EC 233.0 ± 38.4 μS cm^{-1}) from an on-site catchment pond was applied to the field by overhead sprinklers as needed during the study (i.e., up to twice daily during the summer). On 31 Aug. 2011, once the cuttings were successfully rooted, three replications (n = 3) for each of seven fertilizer rate treatments were applied to plots, one replication per row. Plots were left unfertilized (i.e., 0 g m^{-2} N control), or fertilized by evenly spreading one of the following six fertilizer rate treatments: 5, 10, 15, 20, 25, 35 g m^{-2} N of Nutricote® Total 18–6–8 with minor nutrients 100 day controlled-release fertilizer (Plant Products Co. Ltd., Brampton, ON) per plot. Mean monthly air temperatures during the study ranged from 23.7 °C to 2.4 °C in July and January 2012, respectively.

Measurements were made monthly, between Aug. and Nov. 2011 and Mar. and July 2012, as environmental conditions permitted. Proportion vegetative coverage per plot was visually estimated by comparing vegetation-covered to non-covered areas, based on standard area references, by the same evaluator for the duration of the study to ensure consistency. Based on grower standards, plots were visually evaluated monthly, by the same evaluator to ensure consistency, to determine production completion. Vegetative coverage for individual *Sedum* spp. within plots was evaluated using the same method, and the same observer evaluated vegetative coverage at all time points to ensure consistency. Plant growth was evaluated by measuring vegetative shoot height, and inflorescence height and width in two perpendicular directions (i.e., d_1 and d_2) for three representative shoots and inflorescences per plot, for the three most prevalent species (i.e., *S. acre*, *S. spurium* and *S. spurium* 'Tricolor'). Inflorescence canopy area (A) was calculated by the following equation: $A = \pi \times 1/2\ d_1 \times 1/2\ d_2$. Leaf color of *S. acre* shoots was quantitatively evaluated as hue angle at three locations per plot using a colorimeter (Minolta CR-310; Minolta Camera Co. Ltd., Osaka, Japan). On 25 May 2012, all weeds were harvested from individual plots and dried at 70 °C ± 5 °C. Once a constant weight was achieved, weed dry weight per plot was measured. Above-ground dry weight of *Sedum* spp. was not evaluated since a post-production green roof installation was planned for treatment plots.

All data sets were analyzed using GraphPad Prism version 5.03 (GraphPad Software Inc., La Jolla, CA). A two-way repeated-measures ANOVA with a Bonferroni post-test was used to evaluate differences among treatments over time for normalized data of vegetative coverage, shoot height and leaf color. Regression analyses were used to relate leaf color, inflorescence height and canopy area, and weed dry weight to fertilizer rate and to estimate regression parameters for the best-fit regression model (linear or quadratic). Regression models for leaf color, inflorescence height and inflorescence canopy area were used to determine the optimal fertilizer rate for maximum greenness and inflorescence parameters and to estimate the fertilizer rate range at which 95% of the maximums would occur. A Pearson correlation was used to relate weed dry weight to vegetative coverage and fertilizer rate. All data were evaluated using a significance level of $P < 0.05$.

3. Results and discussion

3.1. Vegetative coverage per plot

The interaction between time and treatment influenced total vegetative coverage within plots during production ($P < 0.05$). Over time, total vegetative coverage increased in all treatments (Fig. 1). Although total vegetative coverage was not different among