Testing Green Roof Media for Nutrient Content©

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Green roofs hold great promise as a stormwater best management practice (BMP) but one of the potential issues with their use in areas where runoff quality is a concern is managing the nutrient content of the media. Clearly, sufficient plant nutrients must be present to support a healthy plant community, but excess nutrients should be avoided to reduce runoff quality impacts of the green roof. To date, no standards exist for evaluating nutrient content in green roofs. This study evaluated the nutrient content, as measured by the Saturated Media Extract (SME) procedure of over 30 established green roofs in the United States.

Sampled roofs included a range of media depths (3–13 inches), year of establishment (2002–2006), plant community types, and building settings. Plant community data including surface coverage, weed and moss surface coverage, and dominant species were correlated with nutrient content data to develop a set of standard values for test results. For example, to improve plant surface coverage while discouraging moss and weed growth and reducing nutrient-rich runoff, total nitrogen (nitrate and ammonium) content of the SME should be between 1.5 and 3.0 ppm. As a result of this study, a green roof can be tested on an annual basis to determine the need for additional fertilizer. By limiting fertilizer applications to that which is required, excess nutrient runoff can be reduced while making a green roof "greener" by optimizing plant growth. Also, the ability to evaluate the nutrient content of a problem roof to eliminate or confirm plant nutrient status as the source of the problem is now possible.

INTRODUCTION

The use of extensive green roofs as a part of the storm water management plan for developed sites is becoming increasingly common, particularly for green buildings and leadership in energy and environmental design (LEED) projects. These roofs provide many benefits including reduced air-conditioning costs, increased roof longevity, and improved aesthetics. One of the primary benefits of green roofs is in helping to manage storm water runoff, where green roofs have been shown to reduce the total quantity of runoff by as much as 60% annually, and as much as 90% during summer months (Denardo et al., 2005). Questions remain however, as to the affects of green roofs on runoff water quality. The results of studies of runoff quality suggest that in some cases and with some nutrients and pollutants, quality is improved while other studies have shown increased nutrient concentration in runoff from green roofs (Berghage et al., 2007; Van Setters et al., 2007).

The consensus of researchers is that the nutrient load of green roof runoff is to a large extent determined by the organic component of the medium and the fertilization practices. It is necessary to maintain sufficient nutrient content in the green roof to support the plant community; however, it is not clear what a deficient, sufficient, or excessive nutrient content is, or what test(s) should be used to evaluate nutrient content. In the greenhouse and nursery industries, soil and medium testing procedures have been developed to allow a grower, or a grounds maintenance manager, to test fertilizer nutrients and evaluate the need for additional applications. The most commonly used test for greenhouse and nursery media is the Saturated Media Extract (SME) method (Berghage et al., 1987). In this test, a sample of the medium is brought to saturation with deionized water containing a small amount of diethylene triamine pentaacetic acid (DTPA) to enhance extraction of micronutrients, allowed to equilibrate, and then the liquid is filtered off and tested for various nutrient components including N, P, K, Ca, Mg, Fe, Mn, Zn, and Cu. The results of the tests are compared to standards for the crops and systems being evaluated and fertilizer or compost applications are made to optimize crop growth and minimize waste.

Without sufficient data for green roof nutrient standards, it is hard to compare green roof SMEs to a standard in order to determine appropriate fertilizer applications for green roofs. Test results for organic matter content in the media are also difficult to interpret because there is currently no data available on the long-term stable organic matter content of these media. Although there are German standards for initial organic matter content of the media, these standards are rather high and likely contribute greatly to nutrient runoff during the first several years after installation. The lack of standards greatly limits the value of these tests and makes it difficult to manage a green roof to minimize runoff while maintaining a healthy plant community.

The purpose of this project was to begin to develop standards for green roof organic matter content and for nutrients in SMEs of green roof media.

MATERIALS AND METHODS

Fifty media samples from existing roofs of various ages, conditions, media depths, media components, geographic locations, and plant communities were collected during the summer of 2007. Samples were analyzed for organic matter and SME nutrient content by The Penn State Agricultural Analytical Laboratories using standard lab methods (www.aasl.psu.edu). The SME tests included pH, soluble salts, nitrate, ammonium, phosphorus, potassium, calcium, magnesium, boron, copper, iron, manganese, sodium, and zinc. In addition to media samples, roofs were evaluated for percent coverage by plants, weeds, and moss or clover by using a grid system. Additional data was collected on each roof including construction date, media depth, drainage depth, planting method, irrigation type, building height, and location. Of the 50 samples collected, 14 were of drainage materials rather than media samples and thus were excluded from the analysis. Six additional samples were excluded from the analysis, three that were constructed in 2006 due to a significantly lower amount of plant coverage, and three due to incomplete plant coverage data, leaving 30 samples used for the analysis. Saturated media extract test results were correlated with plant coverage, weed coverage, moss and clover coverage, roof age, and media depth. Results for each nutrient, pH, soluble salts, and organic matter tests were correlated with plant coverage and where significant correlations were found, linear or non-linear curves were fit to the data using regression or non-linear least squares curve fitting.

RESULTS AND DISCUSSION

Plant, Weed, or Moss and Clover Coverage. Plant coverage, weed coverage, or moss and clover coverage were not influenced by media depth for roofs constructed between 2002 and 2005 (Fig. 1). The three sampled roofs constructed in 2006 had lower plant coverage and were thus excluded from the analysis. The average plant coverage for all the roofs, excluding 2006, was 72% with a maximum coverage of 95%. To determine the maximum response for subsequent nutrient analysis, an average was taken of the top 25% of the roofs surveyed and was calculated at 88% plant coverage. By considering a 20% reduction as a reasonable threshold for impact, a threshold value of 70% plant coverage was determined and used to evaluate nutrient affects on the roof.

Within the different media depths, no significant differences were found in plant and weed coverage. Moss coverage increased in the roofs with media depths of 6 inches or more; although, small sample sizes for these greater depths suggest that caution should be exercised in drawing any conclusions from this observation.

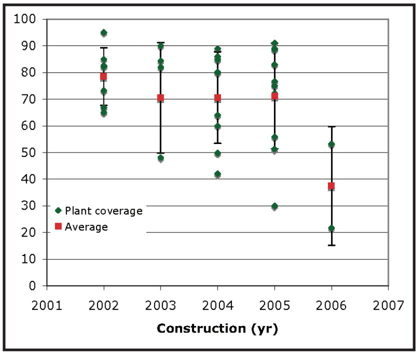

Figure 1. Plant coverage (%) of roof surface for 33 roofs constructed between 2002 and 2006.

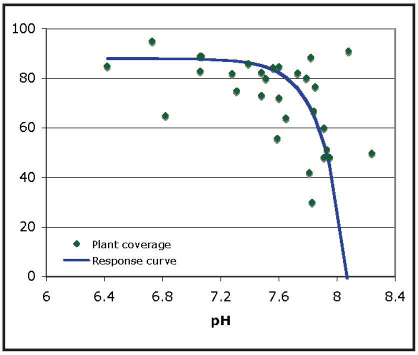

Figure 2. Saturated media extract sample pH and plant coverage for 30 green roofs.

Organic Matter. The average organic matter content of the roof samples was 4.9%. There was a general trend (not statistically significant) to increased plant coverage with increased organic matter. Organic matter content was influenced by roof age, as roofs constructed in 2002 had a slightly higher average organic matter than those constructed in 2003–2005. More sampling is needed to determine whether this is an actual trend or an artifact of the sampled roofs. From these data, it can be concluded that an established plant community can maintain about 5.0% organic matter in the media. For increased plant coverage without excess nutrient leaching, optimum organic matter levels in green roofs was established to be between 4.0 and 6.0%; although, a wider range of 1.0 to 8.0% also showed positive results.

pH. This study showed that as the pH increased and became more alkaline, plant coverage decreased (Fig. 2); conversely, there were no significant correlations between weed coverage and pH. Although not significant, moss and clover coverage increased with a higher pH. Again using the 20% reduction in coverage as a reasonable threshold value for impact, a pH threshold value of 7.8 was determined for optimal plant coverage. These data showed that a higher pH decreased plant growth while no reduction in plant coverage was observed in the acid end of the pH scale; thus, no low pH threshold was assigned based on this project. The lack of a low pH response was likely due to the limited number of samples rather than an ability of these plants to grow well at a low pH and more studies are needed to determine a minimum threshold value.

Based on this project, the recommended pH range for a green roof SME was calculated to be between 6.5 and 7.8, with values in excess of 7.8 being potentially toxic. Although this response was statistically significant, due to the nature of this project, the pH responses could potentially be from unknown factors that vary with pH rather than due to the pH.

Soluble Salts. Based on these data, there was no correlation between soluble salt levels and plant coverage, weed coverage, or moss and clover coverage. Soluble salts are often used as a general evaluation for total fertility in greenhouse and nursery media and low salts indicate low fertility while high salts can indicate over-fertilization and can lead to reduced plant growth.

The observed soluble salt levels in the green roofs tested ranged between 0.76 and 3.9 $MS \cdot cm^{-1}$ but no low or high threshold values could be determined. Nevertheless, a provisional recommended soluble salt range was determined to be 0.4 to 0.7 $MS \cdot cm^{-1}$ with no indication of lower or upper limits.

Nitrogen. Overall, plant coverage increased as total nitrogen (nitrate + ammonium) levels increased and a significant nonlinear relationship between nitrogen and plant coverage was found, but only when the two samples with total nitrogen over 11 $mg \cdot L^{-1}$ were excluded from the analysis (Fig. 3). The total nitrogen in the SME ranged from 0.66 to 15.37 $mg \cdot L^{-1}$. Nitrate and ammonium response curves were similar to those for total nitrogen with deficient threshold values of 1.0 $mg \cdot L^{-1}$ and 0.37 $mg \cdot L^{-1}$, respectively.

The 20% reduction threshold for plant coverage was 1.4 $mg \cdot L^{-1}$ of total nitrogen. A response curve was fit for plant coverage and showed that plant coverage approached the maximum when total nitrogen was over 4.0–5.0 $mg \cdot L^{-1}$. Weed coverage increased linearly as total nitrogen increased, while moss and clover coverage

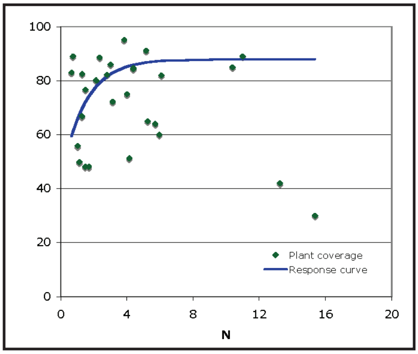

Figure 3. Nitrogen (nitrate + ammonium) in saturated media extract of 30 sampled green roofs and plant coverage.

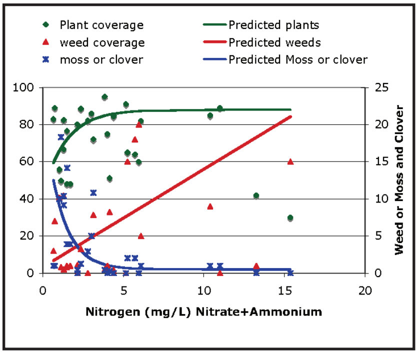

Figure 4. Comparison of plant coverage, weed coverage, and moss and clover coverage with saturated media extract nitrogen test results.

decreased exponentially (Fig. 4). From these trends, recommended total nitrogen in SME of green roof media was determined to be between 1.4 and 4.0 mg·L^{-1}. Nitrogen levels below 1.4 mg·L^{-1} caused decreased plant coverage and increased moss or clover coverage while levels above 4.0 mg·L^{-1} promoted weed growth without significantly improving green roof plant coverage. Excess nitrogen also likely increased nitrogen leaching which results in unnecessary runoff pollution.

Phosphorus. Phosphorus levels in SME of the sampled green roofs ranged from 0.26 to 17.12 mg·L^{-1}. The relationship between phosphorus and plant coverage was similar to that observed for nitrogen (Fig. 5). The 20% coverage reduction threshold suggested that SME levels of phosphorus less than 2.2 mg·L^{-1} were deficient. Weed coverage was not significantly correlated with phosphorus in SME. Moss and clover increased exponentially at phosphorus levels below 5.0 mg·L^{-1}. Based on these samples, phosphorus in SME should be between 2.2 and 4.0–5.0 mg·L^{-1}. Levels below 2.2 mg·L^{-1} may be too low for adequate growth. Levels in excess of 4.0–5.0 mg·L^{-1} did not result in reduced plant coverage; however, as with nitrogen, excess is likely to result in leaching in green roof runoff contributing unnecessarily to runoff pollution.

Potassium. Potassium levels in SME of the sampled green roofs ranged from 3.1 to 34.4 mg·L^{-1}. Although the relationship between plant coverage and potassium was not as strong as with nitrogen or phosphorus, a similar response curve fit to the data indicate a 20% threshold coverage reduction with potassium below about 8.0 mg·L^{-1} (Fig. 6). As with phosphorus and nitrogen, no upper concentration reduction (toxicity level) was found in the samples. The recommended range for potassium in SME of a green roof sample should thus be between 8.0 and 20 mg·L^{-1}, with the upper bound set to reduce pollution in runoff. There were no significant relationships between potassium and weed coverage or moss and clover coverage in the roofs sampled.

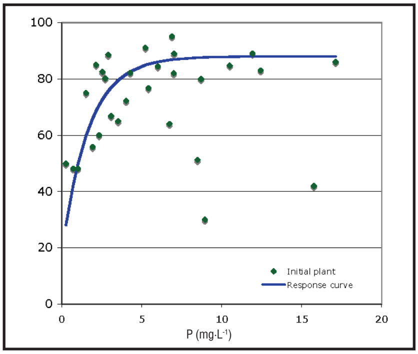

Figure 5. Plant coverage and phosphorus in saturated media extract tests of 30 existing green roofs.

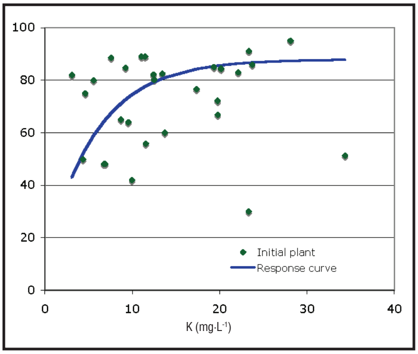

Figure 6. Plant coverage and potassium in saturated media extract test results of 30 established green roofs.

Calcium. Calcium levels in SME of the sampled green roofs ranged from 46 to 212 mg·L^{-1}. There was no significant relationship between plant coverage, weed coverage, or moss and clover coverage and calcium. No low or deficient recommended level can thus be assigned based on these samples. The samples with the highest levels of calcium had reduced plant coverage (Fig. 7); however, these samples also had high pH levels. There is no way to separate these responses and it is possible that the observed decrease in coverage was not related to high calcium, but that high calcium is rather a function of the high pH.

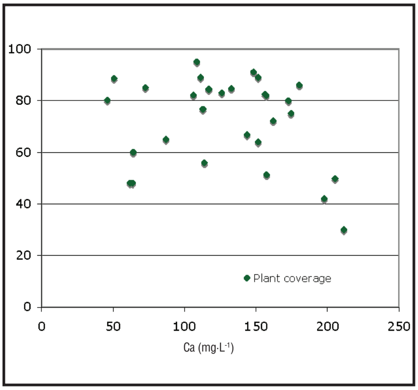

Figure 7. Plant coverage and calcium in saturated media extract of 30 sampled green roofs.

Magnesium. Magnesium levels in SME of the sampled green roofs ranged from 11 to 53 mg·L^{-1}. Plant coverage, weed coverage, or moss and clover coverage were not significantly correlated with SME magnesium levels. Deficiency levels of magnesium were thus below 11 mg·L^{-1} and no upper bound can be suggested.

Boron. Boron levels in SME of the sample green roofs ranged from 0.04 to 0.29 mg·L^{-1}. There was no relationship between boron in SME tests and plant coverage, weed coverage, or moss and clover coverage; although no lower or upper bounds can be inferred from these data. Additional testing is needed to determine the level of boron which is toxic to these plants.

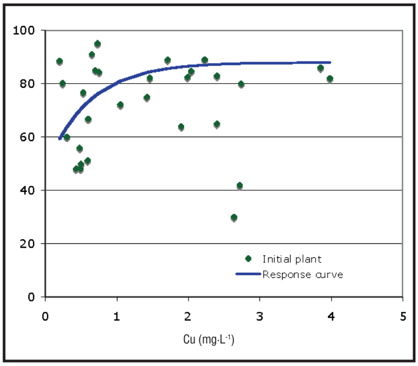

Figure 8. Plant coverage and copper in saturated media extract of 30 sampled green roofs.

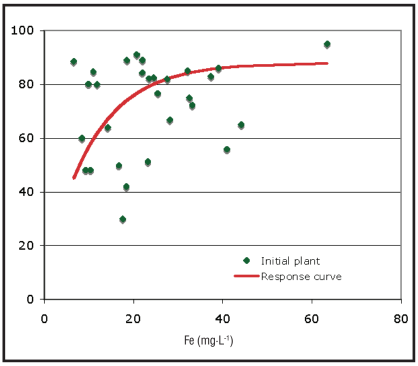

Figure 9. Plant coverage and iron in saturated media extract of 30 sampled green roofs.

Copper. Copper levels in SME of the sample green roofs ranged from 0.2 to 4.0 mg·L^{-1}. The lower bound for copper in green roof SME in this study was 0.5 mg·L^{-1} (Fig. 8). Plant coverage was reduced in roofs with less than 0.5 mg·L^{-1} suggesting the potential for copper deficiency in these roofs. No upper bound is evident in the data, suggesting that toxic levels of copper for a green roof are in excess of 4.0 mg·L^{-1}. Although no upper bound can be suggested, based on plant growth a range between 0.5 and 3.0 mg·L^{-1} might be suggested to optimize plant growth while limiting copper leaching from the roof in runoff.

Iron. Iron levels in SME of the sampled green roofs ranged from 6.6 to 63.4 mg·L^{-1}. The data suggest that iron in SME below 15 mg·L^{-1} might be insufficient for good plant growth and coverage (Fig. 9). No upper bound was suggested by the data. Recommended iron in green roof SME test results for established roofs should thus be between 6.0 and 40 mg·L^{-1} to optimize growth and limit environmental contamination.

Manganese. Manganese levels in SME of the sampled green roofs ranged from 0.6 to 17.6 mg·L^{-1}. Deficiency is suggested at manganese levels below 1.0 mg·L^{-1} by reduced plant coverage (Fig. 10). No upper bound is suggested by the data. Recommended manganese in SME test results for green roof media should thus be between 1.0 and 4.0 mg·L^{-1}.

Sodium. Sodium levels in green roof SME test results ranged from 4.3 to 30 mg·L^{-1}. There was no relationship between plant or weed coverage and sodium in the media sampled; however, moss and clover coverage increased with higher sodium levels. Recommended sodium in SME of green roofs should thus be less than 20 mg·L^{-1} (Fig. 11).

Zinc. Zinc levels in green roof SME ranged from 1.0 to 47.3 mg·L^{-1}. Plant coverage, weed coverage, or moss and clover coverage were not significantly correlated with zinc. Recommended zinc in SME should thus be between 1.0 and 10 mg·L^{-1} to provide for good growth while limiting runoff.

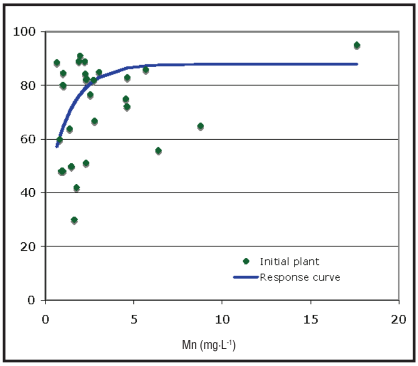

Figure 10. Plant coverage and manganese in saturated media extract of 30 sampled green roofs.

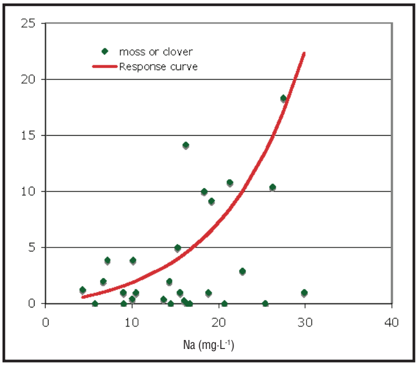

Figure 11. Moss and clover coverage and sodium concentration in saturated media extract of 30 sampled green roofs.

CONCLUSIONS AND SUMMARY

This project provides preliminary nutritional standards for SME tests of existing green roofs (Table 1). These standards allow interpretation of SME test results for green roof media that was not possible prior to this study. Building managers and maintenance staff now have the ability to submit regular media samples to determine the need for various fertilizer nutrients. This makes long-term management of the green roof easier and can be a powerful tool to reduce or eliminate the application of excess fertilizer nutrients that might contribute to runoff contamination. These standards also allow consultants and other professionals called in to evaluate and fix green roof problems to use SME test results as an aid in diagnosing of plant growth and health problems. This is an important development for the green roof industry because it addresses a potential limitation to the use of green roofs to meet total maximum daily load and other runoff standards and can help to make green roofs a better BMP for storm water management, increasing the potential market for these systems.

LITERATURE CITED

Berghage, R.D., D.M. Krauskopf, D.D. Warncke, and **I. Widders.** 1987. Micronutrient testing of plant growth media: Extractant identification and evaluation. Comm. Soil Sci. and Plant Anal. 18:1089–1109.

Berghage, R.D., D.J. Beattie, A.R. Jarrett, and **T. O'Connor.** 2007. Greenroof runoff water quality. Proceedings: Greening Rooftops for Sustainable Communities, Minneapolis, Minnesota.

Denardo, J.C., A.R. Jarrett, H.B. Manbeck, D.J. Beattie, and **R.D. Berghage.** 2005. Stormwater mitigation and surface temperature reduction by green roofs. Transactions Amer. Soc. Agric. Eng. 48(4):1491–1496.

Penn State Agricultural Analytical Services Laboratory. 2008. <www.aasl.psu.edu>.

Van Setters, T., L. Rocha, and **G. MacMillan.** 2007. Evaluation of the runoff quantity and quality performance of an extensive green roof in Toronto, Ontario. Proceedings: Greening Rooftops for Sustainable Communities, Minneapolis, Minnesota.

Table 1: Recommended interpretations for saturated media extract test results from established green roofs.

Nutrient or Test	Low or deficient	Desirable range	High or toxic	Comments
Organic matter	< 1%*	1-6%	> 8%*	High levels are not toxic but may contribute to nutrient runoff
pH	Unknown	6.5–7.8	> 7.8	High levels reduce plant coverage
Soluble salts ($MS \cdot cm^{-1}$)	< 0.4*	0.4–0.8	Unknown	Levels above 0.8 may not be toxic but may suggest potential for nutrient runoff
Nitrogen ($mg \cdot L^{-1}$) (Nitrate + ammonium)	< 1.4	1.4–4.0	> 4.0	Excess N encourages weed growth and runoff contamination without improving plant coverage
Nitrate ($mg \cdot L^{-1}$)	< 1.0	1.0–4.0+	> 4.0	
Phosphorus ($mg \cdot L^{-1}$)	< 2.15	2.15–5.0+	> 5.0	High levels are not toxic but may contribute to nutrient runoff
Potassium ($mg \cdot L^{-1}$)	< 8.0	8.0–20.0	Unknown	High levels are not toxic but may contribute to nutrient runoff
Calcium ($mg \cdot L^{-1}$)	< 40.0*	40.0–180.0	> 180+	
Magnesium ($mg \cdot L^{-1}$)	< 11.0	11.0–53.0+	Unknown	High levels may not be toxic but may contribute to nutrient runoff
Boron ($mg \cdot L^{-1}$)	< 0.04*	0.04–0.2+	> 0.2*	High B is toxic to most plants
Copper ($mg \cdot L^{-1}$)	< 0.4*	0.5–3.0	> 4.0*	High levels may not be toxic but may contribute to nutrient runoff
Iron ($mg \cdot L^{-1}$)	< 15.0*	15.0–40.0+	> 60.0*	Levels between 40 and 60 may not be toxic but may contribute to nutrient runoff
Manganese ($mg \cdot L^{-1}$)	< 1.0*	1.0–4.0+	> 17.0*	Levels between 4 and 17 may not be toxic but may contribute to nutrient runoff
Sodium ($mg \cdot L^{-1}$)	None	0.0–20.0	> 20.0	High Na may promote moss and clover
Zinc ($mg \cdot L^{-1}$)	< 1.2	1.2–10.0	> 12.0*	

*Further testing is required to determine statistical validity of this value.