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Session 3.1: Runoff Quality and Quantity

WHAT IS THAT RUNNING OFF OF MY GREEN ROOF?

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Abstract

Our green roof experiments are designed to evaluate and improve the environmental performance of green roof systems. We have collected storm water samples from two fully-replicated green roof experiments and have determined that there are significant differences in water quality. In storm water runoff from green roof systems that have utilized water soluble fertilizers we have found elevated nitrate levels. In the same experiment, nitrate levels in storm water runoff vary with growth medium depth. In growing medium mixes with high levels of organic matter we have found high levels of nitrate in runoff and also high organic matter content with a high biochemical oxygen demand (BOD). In a recycled glass growing medium we have found that the runoff pH is elevated to a high basic level and that Fe levels exceed the recommended levels for effluent by the Illinois EPA. We continue to evaluate growing medium blends and other green roof components to strive to find the best system that reduces the environmental impact of green roof systems.

INTRODUCTION

Because of inadequate drainage systems and the many contaminants that may be carried within rainwater, storm water runoff can be problematic for heavily populated areas. As a consequence of greater impervious surface area impeding water infiltration, runoff is observed in higher volumes from cities than is found in natural areas of the same size. Urban storm water runoff carries within it toxic chemicals, oil and grease, pesticides, heavy metals, and other contaminants (1). Since pollutants from non-point sources flow into drainage systems and subsequently to rivers and streams (2), both wildlife habitats and drinking water are affected (3).

Investigations have revealed metal contributions to storm water runoff flowing from traditional rooftops. In a recent study, measurable concentrations of heavy metal contaminants (e.g., Cu, Zn, Pb, and Cd) were found in roof runoff from traditional tile, polyester, and gravel roofs (2). The dynamics of the heavy metals with respect to runoff depended in large part on the characteristics of the element and nature and composition of the traditional roof (2). Cu and Zn are essential micronutrients required for growth of organisms; however, there is concern when concentrations of these metals elevate to that of toxicity for living organisms (4). In contrast, Pb and Cd are not required for growth and are considered toxic to human health and aquatic life at any level (4). Contamination of soils and waters by these metals through a number of anthropogenic activities has created environmental health risks.

To address water contamination problems, there are local, state, and federal government regulations. Nationally, Total Maximum Daily Loads (TMDLs) define the total pollutant loading that a waterbody can receive and still meet water quality standards and allocate a specific pollutant wasteload to explicit point and non-point sources (5). When TMDLs are implemented, the storm water wasteload allocation is put in place via the National Pollutant Discharge Elimination System (NPDES) storm water permitting system (5). Several states and the USEPA have used a variety of methods to develop storm water source TMDLs during the past decade (5); however, the USEPA's guidance regarding enforcement of TMDLs has not adequately covered methods to improve waters impaired by non-point sources (5) such as runoff from roof surfaces. Attempts to comply with TMDLs include installation of filters in curb inlets throughout urban areas or other Best Management Practices (3).

To prevent further degradation of water quality in Illinois, many small businesses are required by the IEPA to obtain National Pollutant Discharge Elimination System (NPDES) permits and to develop Storm Water Pollution Prevention Plans (SWPPPs) (1). Through IEPA Title 35: Subtitle C, effluent standards exist that prescribe the maximum concentration of contaminants that are allowed to be discharged into the waters within Illinois. These stipulations define the regulation of contaminants such as heavy metals, bacteria, fertilizers, oil, and sludge (Title 35 Sub Section C: Water Pollution).

Alongside governmental prevention plans, several remediation techniques have been investigated to address the rising number of heavy metal contaminated sites. Most traditional remediation methods, for instance, soil washing/flushing, vitrification, electrokinetics, incineration and landfilling, are extremely expensive to implement (6) and do not address urban problems like lost green space, restoration of lost habitat, and the urban heat island effect. To positively reduce the amount of contaminants found in urban storm water runoff, ecological studies show there may be more inclusive techniques to solve the problem. One prominent example is green roof technology.

Negative effects of storm water runoff volume and quality associated with densely populated areas may be minimized using green roofs. An early examination of storm water runoff from traditional roof surfaces revealed higher concentrations of several heavy metals and nutrients in traditional roof storm water runoff than was found in the rainfall itself (2). The increase in metal concentrations is believed to be caused by rain picking up particulates that have settled on the traditional rooftops between rain events (10) or from the roofing materials themselves. A green roof, through a variety of physical, biological, and chemical processes that filter pollutants and reduce the volume of runoff, may also reduce the amount of pollution delivered to the local drainage system, and, ultimately, to receiving waters (7). However, this ability of a green roof to reduce contaminant concentration in storm water runoff is still subject to ongoing research and is somewhat controversial. It has been suggested that green roofs do not improve runoff quality (8) and may be a source of contaminants (9). An investigation conducted in Canada during September and October of 2004 revealed greater concentrations of Cd, Cu, and Pb in storm water runoff from a green roof than from a control roof and collected rainfall (11). Fertilized vegetated roofs in Europe have also been found to behave as a sink for nitrogen and as a source for nutrients such as potassium and phosphorus (9).

Besides contaminants in the rainfall itself, there are three potential sources of contaminants in the green roof media – inorganic media materials, organic amendments, and fertilizers. Often incorporated into planting substrates to provide a better environment for roots, soil amendments can be any material added to a soil to improve physical properties such as water retention, permeability, drainage, aeration, and structure (12). Soil amendments may be either organic or inorganic. Organic amendments are derived from something that was or is living material while inorganic amendments have been mined or are man-made (12). Examples of organic amendments include peat moss, wood chips, grass clippings, straw, compost, manure, biosolids, sawdust, worm castings, and wood ash. Inorganic amendments consist of vermiculite, perlite, tire chunks, pea gravel and sand (12) as well as the mineral matter that makes up the bulk of the green roof media. At a minimum, organic content of the growing media impacts the visual appearance of the storm water runoff (13; Figure 1a,b)

The choice of fertilizer type influences concentrations of certain contaminants introduced into water runoff and how often one must reapply nutrients. Green roofs have been observed to contribute potassium and phosphorus to runoff; in addition, there may be a potential release of organic nitrogen (9). Continuous-release plant foods (slow-release fertilizers) are coated with a thin permeable membrane that allows either one or all of the nutrients to be allocated into the soil in a controlled manner (14). When a fertilizer is water soluble (water release), nutrients are immediately available to plants through roots and leaves (14), but also have the potential to leach out of the system with the storm water runoff.

According to Ed Snodgrass at Emory Knoll Farms, “we use green roofs to retain storm water, we design green roofs to dampen peak flow, and we hope that green roofs will help with water quality” (15). While we still have a lot to learn, many green roof studies have quantified the components (growth media blend, species mixture, drainage layer, etc…) of a green roof system that contribute to reducing the volume of storm water runoff and damping peak flow. However, there are few investigations that quantify the water quality of the storm water runoff from green roofs and evaluate the contribution of the various components (growth media blend, species mix, drainage layer, fertilizer etc…) to downstream water quality effects. Knowledge of contributions of the various components of a green roof system to the downstream water quality will be extremely useful in development and installation of green roofs with low environmental impact. The Green Roof Environmental Evaluation Network (G.R.E.E.N.) is evaluating water quality from storm water runoff from green roof systems with differing growth media blends, growth media depths, and fertilizer inputs. This paper presents the initial results regarding nitrate concentrations, pH, metal concentrations, and biochemical oxygen demand (BOD) of storm water runoff from varying green roof systems.

MATERIALS AND METHODS

Experimental design – green roof systems

Green roof models were previously established at the SIUE Environmental Sciences Field Site in two completely randomized experimental designs (16,17; Figure 2). A separate water collection system is present for each of the 66 individual green roof models. There are four control roofs with black EPDM membrane surfaces included in the experimental design. Green roof models were planted with five *Sedum hybridum immergrauch* plants per model in 2005 and fertilized at planting with IBDU® (31-0-0; 7.2 g IBDU®/plant; 97 g IBDU®/m^2) in September 2005 and again with IBDU® (31-0-0; 7.2 g IBDU®/plant; 97 g IBDU®/m^2) in May 2006 and with Scott's Nutricote® (540 formulation; 18-6-8; 5 g Nutricote®/plant; 67 g Nutricote®/m^2) in June 2007. Since project establishment, every time there was a precipitation event, storm water flowing through each individual model system was collected in polypropylene gas cans and the quantity of storm water runoff from each green roof system was determined. Storm water runoff through the planted green roof systems is reduced between 40 and 60% of total precipitation, regardless of growing media depth or composition (16,17). Growth media is comprised of 80% Arkalyte and 20% composted pine bark at four media depths (5, 10, 15, and 20 cm) in individual built-in-place green roof systems in one study. In the other study, individual Green Roof Blocks™ are filled with 10 cm of growth media comprised of 80% inorganic material – Arkalyte, Glass, Haydite, Lava, or Pumice – and 20% composted pine bark or the commercial blend, Rooflite.

Analysis of nutrients in storm water runoff

Water samples were collected from the collection container of each model green roof and control roof in 250 mL Nalgene bottles following a precipitation event on July 2, 2007. Sample analysis occurred within 12-hours of collection. Samples were analyzed for nitrate concentration and pH using a Fisher Scientific Accumet XL25 pH/mV/Ion meter with combination nitrate ion electrode, pH electrode, and temperature probe. Standard methods described in the Fisher Scientific Accumet XL25 instruction manual were followed for both nitrate and pH analyses.

Analysis of metals in storm water runoff

Using 500 mL Nalgene collection bottles, storm water runoff samples were collected from the collection container of each model green roof and control roof on June 27, 2007 and transported to the SIUC plant physiology lab for analysis. Nalgene collection bottles were pretreated by acid washing overnight and rinsing with Millipore water. To remove any biomatter present in water samples collected, samples were filtered to 0.45 microns prior to analysis using atomic absorption spectrophotometry (Model 220FS, Varian, Inc.).

Analysis of Biochemical Oxygen Demand (BOD) in storm water runoff

In the research laboratory, standard 15-cm greenhouse pots were filled to a growing media depth of 10 cm with four blended (80% inorganic material:20% composted pine bark; Arkalyte, Bottom Ash, Haydite, or Lava) or two commercial (MidWest Mix or Rooflite) growth media blends. In this laboratory experiment, there were 6 replicate pots per media blend. Filled pots were placed in rinsed/dried pails and 500 mL of tapwater was poured over the media and “leachate” was collected in the pail over a 20 minute period. Collected “leachate” was poured into standard BOD test bottles and the initial dissolved oxygen (DO) content was measured. Bottles were stored in the dark under a box on the lab bench for seven days and the DO was re-measured. BOD was calculated by subtracting the final DO from the initial DO. Tapwater BOD was also determined by this method.

All recorded data has been analyzed using SAS 9.1 to determine whether or not there are differences in nitrate concentration/pH/heavy metal concentration/BOD among the different green roof systems (ANOVA for a completely randomized design, $\alpha < 0.05$).

RESULTS AND DISCUSSION

Initial collections of storm water runoff (Figure 1a,b) presented a clear visual indication early in the study that there may be differences in water quality dependent upon media formulation or media depth. Our recent laboratory analysis of green roof water quality indicates clearly that there are nutrient, pH, metal, and BOD differences (Figure 3-7) in storm water runoff from varying green roof systems. Further, these differences can be attributed to differences in growth media composition, growth media depth, and fertilization as described below.

The nitrate concentration in the storm water runoff from the green roofs was elevated compared to the nitrate in the runoff from control (EPDM) roof models as determined in July 2007 (Figure 3). There are no standards currently for the water quality of roof (traditional or green roof) or urban runoff, thus results can only be compared to reference standards for water quality (9). Therefore, nitrate concentration in the runoff from control roof models (approximately 4 ppm) in this study is less than the EPA drinking water standard (10 ppm). However, nitrate in storm water runoff from built-in-place systems with 5 and 10 cm of (80% Arkalyte:20% composted pine bark) growth media and Green Roof Blocks™ containing 10 cm of the same growth media blend was approximately the same as the EPA drinking water standard, but greater than runoff from control roofs. Nitrate in storm water runoff from Green Roof Blocks™ containing 10 cm of six different growing media compositions also varied greatly (Figure 4). Nitrate in storm water runoff from Green Roof Blocks™ containing either 10 cm of Arkalyte, Haydite, or Pumice (80% inorganic material:20% composted pine bark) growing medium blends was again approximately the same as the EPA drinking water standard. However, nitrate in storm water runoff from Lava (80% inorganic material:20% composted pine bark) and Rooflite (commercial blend) growing medium was approximately 3 times the EPA drinking water standard and greater than runoff of control roofs. Further, nitrate in storm water runoff from recycled glass (80% inorganic material:20% composted pine bark) growth media was approximately 5 times the EPA drinking water standard. It is too early in our investigation to attribute the nitrate in the storm water runoff entirely to the fertilization regime that was used in our study (models fertilized twice with IBDU® and once with Nutricote®). We are still analyzing the composition of the inorganic and organic materials in the growth media in our laboratory. However, nitrate levels in green roof storm water runoff were previously reported as either the same as the precipitation (18), being retained by the green roof (9), or as being released from recently fertilized green roof systems (9). In the study which previously reported nitrate as being either retained or released from green roof systems, the green roofs were fertilized in Spring 2001 and 2002 with a blend of 50% Multicote® 8 extra (18-6-12) and 50% ProMagna® (11-5-18) at a rate of 35 g blend/m^2 (9). The Multicote® 8 extra is similar to the Nutricote® 540 that we have used in that it is a slow release (8 months for the Multicote®; 18 months for the Nutricote®) and the ProMagna® is easily dissolvable as is the IBDU® we utilized which is water soluble. It is very apparent that fertilizer selection and timing is an important determinant of water quality of green roof storm water runoff. We are awaiting a Nutricote® 720 – which we understand will be available next year – which would perhaps slow the release of nutrients into the storm water runoff.

As stated previously, there are no standards currently for the water quality of roof (traditional or green roof) or urban runoff, thus results can only be compared to reference standards for water quality (9). Therefore, while there were differences in zinc [Zn] and copper [Cu] concentrations in storm water runoff of control roofs and various growth media depths and growth media, neither [Zn] nor [Cu] in storm water runoff from green roofs exceeded IEPA effluent standards (Figures 5 and 6). However, [Fe] in storm water runoff from the recycled glass media mix exceeded IEPA effluent standards (Figure 6) and the pH of this runoff was also greater than 8.0 (Figure 4). We know that this recycled glass product is treated with lye in the manufacture process which would explain the pH rise, but we do not know where the Fe is "leaching" from. It is very interesting to note in the growth media depth study that [Cu] in storm water runoff was elevated slightly in all but the control roof and Green Roof Blocks™ (Figure 6). Our built-in-place models contain a commercial drainage material (JDR Drain) with a root barrier on top of the drain cups. One plausible explanation is that there is Cu impregnated in this root barrier in each of the built-in-place models – note that there is no drainage layer on the control roof or in the Green Roof Block™ system, hence very little Cu leaches from these systems. In a previous examination of [Cu] concentration from runoff of vegetated roofs in southern Sweden, the [Cu] concentration was elevated compared to non-vegetated roofs and also was attributed to the construction materials (drainage material) of the green roof system (9). Further, there is almost no [Zn] in storm water runoff from any of the Green Roof Block™ models with various growth media types while there is [Zn] in the storm water runoff from the control roof and the other built-in-place models. Apparently a material (likely a roofing sealant) used in construction of these built-in-place green roof models contributes [Zn] to the runoff. Recently, it was reported that storm water runoff from the American Society of Landscape Architects (ASLA) green roof contained Cu, Pb, and As (18). It was speculated that these metals in the ALSA green roof storm water runoff were coming from geotextiles or other roofing materials. No attempt was made to evaluate metal concentration in storm water runoff from a non-green roof in the same study (18) which could have indicated that metals from the roofing materials rather than from the green roof were leaching into the storm water.

Finally, a recent laboratory leaching study found great differences in the BOD of the storm water runoff of the different growth media evaluated (Figure 7). Some of the media blends (Bottom Ash and Midwest Mix) have BODs close to tapwater while others (Rooflite and Arkalyte) have BODs that are much greater. All of the measured BODs are well below typical sanitary wastewater treatment plant effluent limits, which are 20-30 mg/L, but would be near the limits for some sensitive areas, which can be 5 mg/L.

CONCLUSION

The results from the three phases of this study clearly indicate that runoff water quality varies as the components of the green roof system are varied. The goal is to design a green roof "prescription" that will optimize storm water runoff benefits (reducing volume and damping peak flows) while reducing or eliminating water quality impacts. Therefore, we clearly would not recommend the recycled glass growth media blend that we have tested – storm water runoff from this system exhibited high levels of nitrate, pH, and Fe. Ideally we wish to have sufficient elemental, nutrient, and organic components in the growth media that would provide for optimal plant growth and survival – an amount that would also not leach from the media into the storm water runoff and detrimentally impact downstream water quality. Finally, we have not yet evaluated BOD in storm water runoff from green roof models. It is possible that the BOD will go down significantly in a living system. Ultimately, the variability of the data in this study indicates that the planning process for green roof systems must consider the components (growth media blend) and the inputs (fertilizer) in order to prevent contamination of downstream water supplies. We will be continuing our investigations both on our green roof and in the laboratory to aid in the continued development of green roof systems.

LITERATURE CITED

1. Illinois Environmental Protection Agency (IEPA). 2001. www.epa.state.il.us/water/compliance/drinking-water/publications/regulated-contaminants.pdf
2. Mason, Y., Ammann, A.A., Ulrich, A., and Sigg, L. 1999. Behavior of Heavy Metals, Nutrients, and Major Components during Roof Runoff Infiltration. Environ. Sci. Technol., 33(10):1588 – 1597.
3. Hipp, J. A., O. Ogunseitan, R. Lejano, C. S. Smith. 2006. Optimization of Stormwater Filtration at the Urban/Watershed Interface. Environ. Sci. Technol. 40(1): pp. 4794 – 4801.
4. Hornsby Shire Council (HSC). 2004. Stormwater - Metals in Water. Water Quality Monitoring WQM). http://www.hornsby.nsw.gov.au/environment/wqm/process/1sc1.html
5. United States Environmental Protection Agency (USEPA). 2007. Total Maximum Daily Loads with Stormwater Sources: A Summary of 17 TMDLs. Watershed Branch Office of Wetlands, Oceans and Watersheds U.S. Environmental Protection Agency.
6. Wu ,Q. T., Z. B. Wei, Y. Ouyang. 2007. Phytoextraction of Metal-Contaminated Soil by Sedum alfredii H: Effects of Chelator and Co-planting. Water Air Soil Pollution 180:131–139.

7. Low Impact Development Center Inc. (LID) 2007. Benefits of Green Roofs. http://www.lid-stormwater.net/greenroofs/greenroofs_benefits.htm
8. Liu, K. 2004. Sustainable building envelope – garden roof system performance. National Research Counsel, Institute for Research in Construction.
9. Berndtsson, J.C., T. Emilsson, L. Bengtsson. 2006. The influence of extensive vegetated roofs on runoff water quality. Science of the Total Environment. 355:48-63.
10. VanWoert, N.D., D.B. Rowe, D. Bradley, J.A. Andresen, C. L. Rugh, R.T. Fernandez, L. Xiao. 2005. Green Roof Stormwater Retention: Effects of Roof Surface, Slope, and Media Depth. J Environ Qual. 34: 1036-1044.
11. MacMillan, G. "York University Rooftop Garden Stormwater Quantity and Quality Performance Monitoring Report", Proceedings of the "Green Rooftops for Sustainable Communities", 2nd annual conference, June 2-4, 2004, Portland, Oregon.
12. Davis, J.G. and C.R. Wilson. 2007. Choosing a Soil Amendment. Colorado State University Extension – Horticulture. http://www.ext.colostate.edu/pubs/garden/07235.html
13. Richey, D., K. Forrester, D. Gaffney, V. Jost, K. Luckett, S. Morgan, and W. Retzlaff. 2007. Evaluation of storm water quality from a Midwest green roof system. Transactions of the Illinois State Academy of Sciences. Supplement to Volume 100:38.
14. Osmocote. 2007. Discussion Forum. http://www.osmocote.com/
15. Snodgrass, E. 2007. Green roofs, the blue planet and making choices. Green Roof Infrastructure Monitor. 9:39.
16. Forrester, K., V. Jost, K. Luckett, S. Morgan, T. Yan, and W. Retzlaff. 2006. Evaluation of storm water runoff from a Midwest green roof system. Transactions of the Illinois State Academy of Sciences. Supplement to Volume 100:62.
17. Gaffney, D., V. Jost, K. Luckett, W. Retzlaff, and S. Morgan. 2007. Evaluating storm water runoff from Green Roof Blocks™ with six different growth mediums. Transactions of the Illinois State Academy of Sciences. Supplement to Volume 100:37.
18. Glass, C. 2007. Green Roof water quality and quantity monitoring. http://www.asla.org/land/050205/greenroofcentral.html

Figure 1. a (top) Storm water runoff samples collected from individual green roof systems following a precipitation event. The two bottles on the far left represent runoff from control roof surfaces (EPDM membrane). Growth media depth (3rd number in sequence) increases to the right. The last two bottles have a 20-cm growth media depth and are non-planted (N) or planted (P). Growth media in all green roof systems is 80% Arkalyte and 20% composted pine bark.

Figure 1. b (bottom) Storm water runoff samples collected from individual green roof systems following a precipitation event. The bottle on the left contains runoff from a control roof surface (EPDM membrane). Bottles are labeled by table/position, and inorganic media type (G=Glass, L=Lava, H=Haydite, A=Arkalyte, or P=Pumice; all 80% inorganic material and 20% composted pine bark) or commercial blend (OR=Rooflite) and are non-planted (N) or planted (P).

Figure 2. Green roof experiments (left, growing media depth experiment in built-in-place models; right, different growth media formulations in Green Roof Blocks^{TM}) at the Environmental Sciences Field Site at Southern Illinois University Edwardsville. Each green roof model has a separate storm water collection system so that storm water runoff quantity and quality can be evaluated for each individual system.

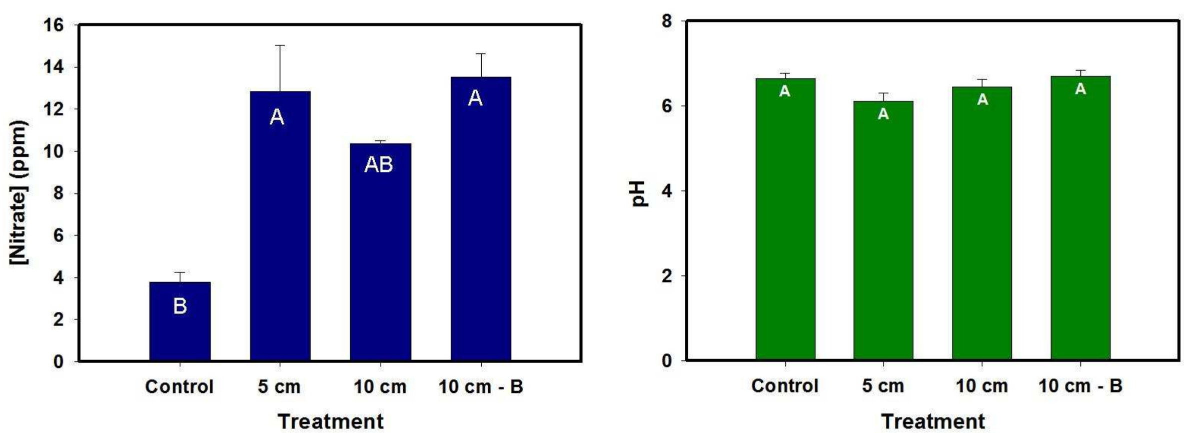

Figure 3. Mean nitrate concentration (ppm) and pH for storm water runoff collected on July 2, 2007 from control roofs, planted 5 cm and 10 cm built-in-place green roofs, and 10 cm Green Roof Blocks™ containing 80% Arkalyte and 20% composted pine bark. Bars with same letter are not significantly different, $p<0.05$. Error bars + 1 SE, n=4.

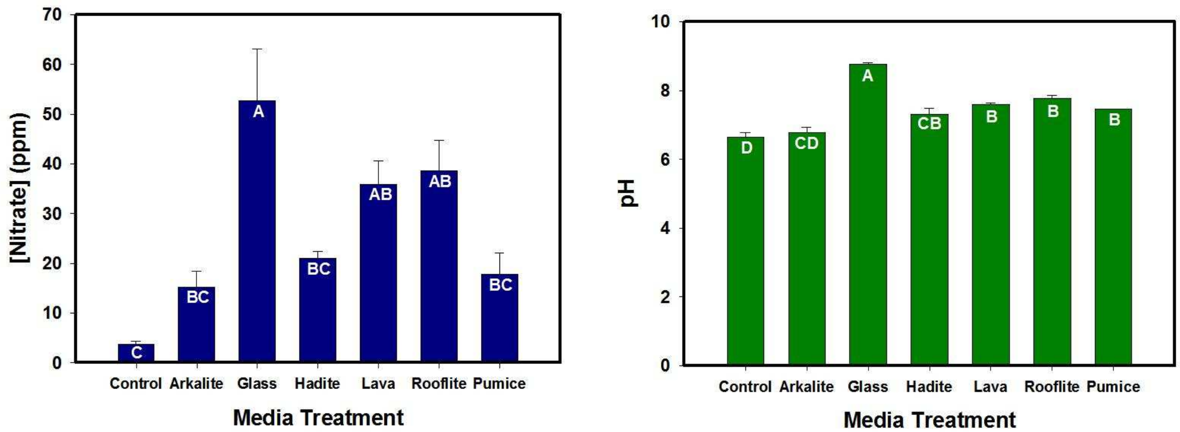

Figure 4. Mean nitrate concentration (ppm) and pH for storm water runoff collected on July 2, 2007 from control roofs and planted Green Roof Blocks™ containing 10 cm of 80% inorganic material (Arkalyte, Glass, Haydite, Lava, or Pumice) and 20% composted pine bark or Rooflite (commercial blend). Bars with same letter are not significantly different, $p<0.05$. Error bars + 1 SE, n=3.

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ERROR: rangecheck
OFFENDING COMMAND: .buildcmap

STACK:

-dictionary-
/WinCharSetFFFF-V2TT786613C3t
/CMap
-dictionary-
/WinCharSetFFFF-V2TT786613C3t
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