RURALS: Review of Undergraduate Research in Agricultural and Life Sciences

Volume 4 | Issue 1 Article 2

July 2009

Analysis of Green Roof Growing Media Porosity

Kelsey Latshaw
University of Nebraska, Lincoln, klatshaw@huskers.unl.edu

Jay Fitzgerald
University of Nebraska, Lincoln (Agronomy and Horticulture Department), jfitzgerald2@unl.edu

Richard Sutton
University of Nebraska, Lincoln (Agronomy and Horticulture Department), rsutton1@unl.edu

Analysis of Green Roof Growing Media Porosity

Cover Page Footnote
This project was made possible through the University of Nebraska, Lincoln Undergraduate Creative Activities and Research Experiences (UCARE) Program, funded by the Pepsi Endowment and Program of Excellence funds. The authors express their gratitude to Dennis McCallister, roofliteTM, and all who contributed to this project. "roofliteTM is standardized green roof growing media available for use on all green roof systems throughout North America. roofliteTM meets American Society for Testing Materials (ASTM) standards, plus the German FLL Green Roof requirements. Precisely designed and manufactured to meet these stringent standards, roofliteTM provides assurance that your green roof vegetation has the ultimate balance of nutrients, water holding capacity, and drainage characteristics to create and promote a sustainable green roof environment" (roofliteTM, 2007).

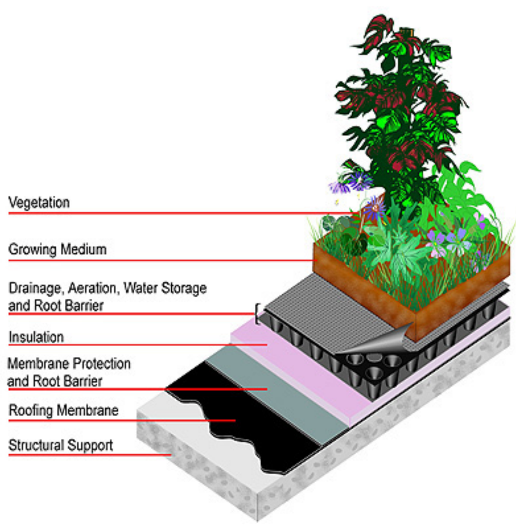
1. Introduction

A green roof (roof with a vegetated surface and substrate) is comprised of structure, decking, and waterproof membrane topped with growing media and plants (Figure 1). Of these, the media is by far the most vital to plant life. For example, several important chemical and physical factors within growing media regulate the ability of a plant to grow and develop. Media must provide water, supply nutrients, permit gas exchange, allow drainage, and support plant roots (Nelson, 1991). Of these functions, adequate drainage and water holding capacity is key for green roof success and will be discussed in detail.

When selecting a growing media for a green roof, a rooftop environment should be distinguished from traditional plant settings. Decreased moisture, drought, extreme temperatures, high levels of wind and solar radiation create hostile locations for plants (Oberndorfer, 2007). It is necessary for green roof growing media to hold adequate nutrients and water for plants to survive. In addition, green roof media should be lightweight and well-drained to alleviate the roof's structural load. Typical green roof growing media (e.g. rooflite™[1]) is composed of inorganic materials (heat expanded shale) with small amounts of organic matter, reducing the saturated weight of the media without losing volume from decomposition (Friedrich, 2005).

Figure 1. Typical green roof structure.

http://www.sbprojectcleanwater.org/images/WQathome/greenroofcartoon.jpg



[1] Manufacturer's name

The depth of the media depends upon the type of green roof system, *extensive* or *intensive*. Intensive green roof systems require 25.40 cm (10.00 in) or more of growing media to support a wide variety of plant species. In contrast, extensive green roofs typically consist of 7.62-15.24 cm (3.00-6.00 in) of media and support a narrow range of plant species (Friedrich, 2005). Unfortunately, applying shallow depths of growing media can lead to decreased water holding capacity and lack of insulation of plant roots from freezing temperatures (Getter, 2006). Consequently, it becomes critical that the media maintains both physical and chemical properties to sustain plant growth in the environment of rooftop gardening (Sutton, 2007).

Rarely is there a correct balance of water for plants, at times it is in excess while at other times it is deficient (Emerson P, 1930). Therefore, the spaces between the particles and within the particles themselves become significant. It is within these pore spaces that roots grow, microbes live, and notably, air circulates and water percolates. Porosity is defined as the ratio of void volume to the total solid volume of a material. Plant roots must access both air and water to survive. As with natural soil, ideally, 50 percent of the growing media should consist of mineral and organic content. The remaining 50 percent should be pore space. In this ideal situation, the pore space present in a growing media would be divided evenly between two fractions—air and water. If water predominates, media becomes heavy and waterlogged. If air predominates, media becomes lighter, but plants may suffer from drought. Consequently, it is necessary for a growing media to have proper drainage, but also sufficient water holding capacity (Fendwick, 1982).

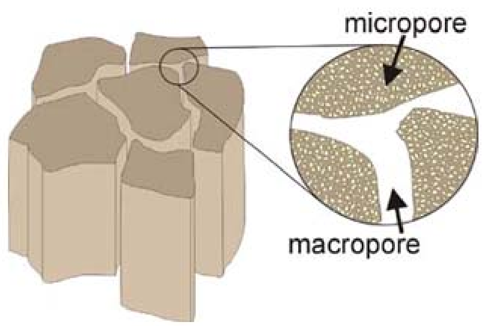
Although it is important to have around 50 percent porosity, pore size is more critical for the growth of plants. While the percent of pores can measure compaction, it may not accurately reflect the soil's structure. Generally, growing media that has a large average pore size will have less total porosity. A media that has a small average pore size will have greater total porosity. (Brady, 2004).

To understand the relationship between water and pore size in a growing media, the following terms are defined. Macropores are pores greater than 0.01 mm. Micropores are pores that measure 0.01 mm or less (Figure 2). Macropores enable quick drainage, allowing gravitational water, air, and carbon dioxide to move through the growing media. Gravitational water is water moving downward through a media under the influence of gravity. In contrast, micropores provide habitat for microbes and hold capillary water. Capillary water is water that is held in a growing media for a longer time due to capillary forces—an adhesive force allowing water to rise and fill pore spaces.

Therefore, the distribution of micro and macropores in a growing media is extremely important. Their balance influences how well water, air, and gas can pass through the media, the amount of excess water that can drain from the media, and

Figure 2. Macropores and micropores in a growing media.

http://www.landfood.ubc.ca/soil200/images/16images/16.1.1macro&micropores.jpg



how much water can be held against the force of gravity (water-holding capacity). A growing media with a balance of pore sizes will hold air and water in nearly equivalent amounts (Handreck, 2002).

Inorganic materials used in green roof media include calcined clay, expanded shale, perlite, pumice, sand, gravel, crushed tiles and brick. Heat expanded shale accounts for 95% of rooflite™'s composition. These materials create a media that is relatively lightweight, porous, less easily compacted, and still provides good root anchorage. The remaining 5%, by volume, organic fraction often consists of compost that retains water and provides nutrients. The biotic compliment of microorganisms found in compost is critical to break down organic material and recycle nutrients (Bunt, 1976).

Heat expanded shale and compost are readily available bulk materials. As green roofs become more common, contractors may wish to utilize these materials in locally blended media. Because of the critical nature of media porosity and its effect on drainage and water availability, tests for amount, size, and distribution of pore space would be necessary. For this experiment, we developed a simple test to calculate the moisture drained and held by a media to determine if a custom blended media can be utilized. The tested growing media, rooflite™, is used here as a surrogate for testing custom media. The main objective of this analysis will be to determine if two depths of media commonly found on extensive green roofs will meet the manufacturer's recorded values regarding porosity and water retention for an extensive green roof system. The two depths of media will also be compared in regards to porosity. Our hypothesis is that rooflite^{TM} will possess an adequate porosity to withstand rooftop conditions (i.e. meet manufacturer's specifications) and that greater depth of media (10.16 cm) will provide significantly greater water retention than a shallower depth (7.62 cm).

2. Materials and Methods

Table 1 lists standard growing media depths for extensive green roofs. These depths are important, as too much media will add excess weight structurally and not enough media will hinder plant growth. For the purpose of this paper, extensive green roof media depths of 7.62 cm (3.00 in) and 10.16 cm (4.00 in) will be compared. The study analyzed rooflite^{TM}, a certified green roof growing media as a surrogate for a generic heat-expanded shale and compost mixture, for its 1) pore space and 2) drainage of free, non-hygroscopic (non-capillary or gravitational) water.

Six quart size 7.62 cm (3.00 x 3.00 in) square milk cartons were cut to a 15.24 cm (6.00 in) height and filled with rooflite^{TM} (Figure 3). A small hole was plugged by a cork in the bottom center of each carton to allow for controlled drainage. Three of the cartons were filled to 10.16 cm (4.00 in), producing 490 mL of media in volume, while the remaining three were filled to 7.62 cm (3.00 in), producing 366 mL volume. The weights of the three 10.16 cm (4.00 in) cartons were equalized by transferring media from one carton to another until they balanced and the dry weight was recorded in grams. The same procedure was applied to the three 7.62 cm (3.00 in) cartons. Each milk carton was then placed over an empty beaker. A graduated cylinder was filled to 250 mL and water was introduced into the media until a thin layer of water measuring 1 mm collected at the top, meaning no additional water could penetrate. The quantity of water each carton could hold was then recorded by subtracting the amount of water left in the graduated cylinder from 250 mL. The media in the cartons were left to absorb the water overnight.

Table 1. Media depths for extensive green roofs.

depth (inches)	
3	very shallow
4	shallow
5	deep
6	very deep

Figure 3. Rooflite^{TM} in experimental carton with removable plug.

Twenty-four hours later, the weight of the media and water was recorded. The cork plugs were then removed, allowing leaching of all free water into the beaker below. When the water stopped draining, the leached water was measured in mL and recorded as gravitational water. The weight of the media without gravitational water was recorded. The capillary water, or the water remaining in the capillary pores of rooflite^{TM}, was calculated by subtracting the gravitational water from the initial amount of water poured into each carton. This determined the water holding capacity of each carton of media.

3. Results and Discussion

To find percent porosity, the amount of water added to each container was divided by the container volume. An average of all 6 containers resulted in 42 percent porosity, compared to rooflite^{TM}'s manufacturer analysis of 53.3 percent porosity. The tested porosity of rooflite^{TM} is low compared to the rooflite^{TM} analysis. This may be a result of the media settling in the containers, or it could relate to a quality control issue in manufacturing rooflite^{TM} in regards to uniformity of particle size. The composition of rooflite^{TM} may contain more than 5 percent compost or the manufacturers may have tested saturation differently. In a perfect scenario, a media would possess 50 percent total porosity. To calculate air-filled porosity, the amount of water drained (gravitational water) was divided by the container volume. The data identified an aeration porosity of 9.5 percent, compared to 25.6 percent from the manufacturer. Again, the calculated value is relatively low. In a completely balanced growing media, both aeration porosity and water-retention porosity should equal 25 percent. In the experiment, aeration porosity could be low since gravitational water is sometimes defined as the excess moisture in a media that percolates within 24-48 hours after a water input event. Since we only waited 24 hours and not 48 hours, extra gravitational water could be lowering the calculated aeration porosity and thus inflating the water-retention porosity. However, twenty-four hours is a more reasonable approximation of roof top conditions for gravitational water drainage, because of evapotranspiration, or the loss of water into the atmosphere from surfaces including soil and vegetation. The manufacturer's analysis tells us that the maximum water-retention porosity ranges from 46.3 to 35 percent (FLL, 2002). When the aeration porosity is subtracted from total percent porosity, a water-retention porosity of 32.5 percent is found. This number is in range with rooflite™'s analysis, but is high for the 25 percent that is ideal. The aeration porosity also seems low while the water-rention porosity appears high. However, in dealing with media depths of 7.62-10.16 cm on rooftop conditions, an extra 12% of water will not last long, again due to evapotranspiration. Although tested pore distribution differs from the rooflite™ analysis, it has been determined that the media can hold and drain enough water on a green roof with a 10.16 cm media depth. Depending on the designer's specifications, it must be determined if differences in porosity from manufacturer's guidelines can be accepted or rejected. In this case, we would accept them, understanding rooftop conditions.

The amount of water held in 10.16 cm of rooflite™ surpasses that of 7.62 cm (Figure 4). (Also see Table 2 under the *capillary H_20* section.) It is clear that gravitational water drained from 10.16 cm of media exceeds that of 7.62 cm. (See *gravitational H_20* heading of Table 2.) Variations within Table 2 were attributed to the lack of uniformity in particular particle size within the samples. Some samples appeared to be composed of a more specific particle size than others. This seems to be an attribute of the physical properties of rooflite™ itself and the distribution of compost and heat expanded shale, which may have changed during handling.

Figure 4. Amount of capillary water held in 7.62 cm of rooflite™ growing media compared to 10.16 cm.

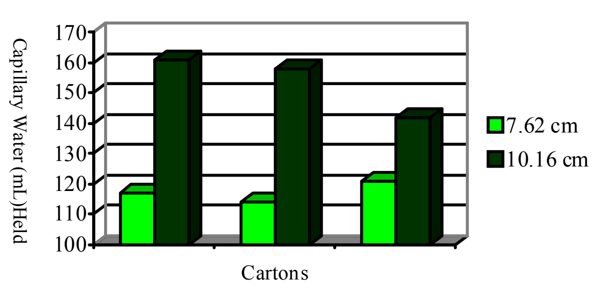


Table 2. Data collected for 7.62 cm and 10.16 cm cartons of rooflite™.

Sample Number	*Media depth (cm)*	*dry weight less carton wt (g)*	*H_2O added (mL)or(g)*	*wet weight (g)*	*gravitational H_2O (mL) or (g)*	*media with capillary H2O (g)*	*capillary H_2O mL) or (g)*	
1	7.62	357.79	151	508.79	34	474.79	117	
2	7.62	368.40	149	517.40	35	482.40	114	
3	7.62	345.87	158	503.87	37	466.87	121	
							117	*Mean*
							4	*StdDev*
							12	*Variance*
1	10.16	489.00	196	685.00	35	650.00	161	
2	10.16	507.38	207	714.38	49	665.38	158	
3	10.16	477.37	196	673.37	54	619.37	142	
							154	*Mean*
							10	*StdDev*
							104	*Variance*

As it applies to green roofs, a greater media depth efficiently retains water, allowing plants to withstand extreme rooftop environments and drain readily to reduce the time roof structure is weight-loaded by water. The 10.16 cm media depth allows more capillary water to be held, so plants can avoid drought by utilizing that source of water. An average of 38.76 mL of water is held per inch of rooflite™, meaning 38.76 mL of water is gained from using a 10.16 cm (4.00 in) media depth instead of a 7.62 cm (3.00 in) media depth. Larger media depths would hold more water, but the weight exerted on the roof must also be minimized. The 10.16 cm depth enables adequate internal drainage, allows for gas exchange and lessons dead weight on the roof. To balance adequate drainage with moisture retention, media composition, as well as depth, is important. A composition consisting of light weight minerals such as heat-expanded shale and 5 percent organic matter reduces mean weight, holds adequate water and promotes internal drainage.

A statistical t-test sampling two unequal variances was applied to the experiment (α=5%) and showed a significant difference between the water held at depth of 7.62 cm and 10.16 cm (Table 4).

Table 4. Statistical data from a t-test assuming unequal variances for two sample sets.

Media Depth	7.62 cm	10.16 cm
Mean Weight (grams)	117	154
Variance	12	104
Observations	3	3
Mean Difference	0	
df	2	
t Stat	-5.83	
P (T<=t) one-tail	0.01	
t Critical one-tail	2.92	
P (T<=t) two-tail	0.03	
t Critical two-tail	4.30	

References

Brady N.B., Weil R.R. 2004: Elements of the Nature and Properties of Soils, Ed 2nd. New Jersey: Prentice.

Bragg, N. 1998: Growing Media. Kent: Nexus Media Limited.

Bunt A.C. 1976: Modern Potting Composts. London: Allen and Unwin.

Emerson P. 1930: Principles of Soil Technology. New York: Macmillan.

Fenwick I.M., Knapp B.J. 1982: Soils Process & Response. London: Duckworth.

FitzPatrick E.A. 1980: Soils: Their Formation, Classification and Distribution. London: Longman

Flegmann A.W., George R. 1977: Soils and Other Growth Media. London: Macmillan.

Forschungsgesellschaft Landschafsentiwicklung Landschaftsbau (FLL). 2002: Guidelines for the Planning Execution and Upkeep of Green-Roof Sites.

Friedrich, Charles R. 2005: Principles for Selecting the Proper Components for a Green Roof Growing Media. In Proc. of 3rd North American Green Roof Conference: Greening Rooftops for Sustainable Communities. 262-273.

Getter K, Rowe B. 2006: The Role of Extensive Green Roofs in Sustainable Development. HortScience 41(5):1276-1285.

Handreck K, Black N. 2002: Growing Media for Ornamental Plants and Turf, Ed 3rd. Sydney: UNSW Press.

Mamo M., Kettler T.A., Sorenson R.C., Dierberger B.S., McCallister D.L. 2007. Soil Resources: A Laboratory Manual. Lincoln: Nebraska Institute of Agriculture and Natural Resources.

Oberndorfer, E. 2007. Green Roofs as Urban Ecosystems: Ecological Structures, Functions, and Services. BioScience 57(10):823-833.

rooflite™. 2007. Certified Green Roof Media. Available at http://www.rooflite.us/ Accessed November 12, 2008.

Sutton, R. 2007. A Prairie Green Roof. Lincoln: Center for Grassland Studies.