Ecological Engineering 91 (2016) 195–206

Contents lists available at ScienceDirect

Ecological Engineering

journal homepage: www.elsevier.com/locate/ecoleng

Stormwater performance of a full scale rooftop farm: Runoff water quality

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ARTICLE INFO

Article history:
Received 31 October 2014
Received in revised form
27 November 2015
Accepted 26 January 2016
Available online 19 March 2016

Keywords:
Green roof
Urban agriculture
Stormwater management
Nutrient leaching

ABSTRACT

A number of benefits have been attributed to green roofs including food production. However, little research has been done to quantify the effects of rooftop farming practices on green roof benefits. The impact of rooftop farming on stormwater runoff is especially important, considering the different nutrient management practices on ornamental and agricultural green roofs. In order to advance knowledge on this potential impact, runoff water quality from a full-scale rooftop farm in Long Island City, Queens, New York, was monitored and compared to runoff water quality from a suite of extensive, sedum green roofs, also located in New York City. Samples of runoff water and rain were collected and analyzed for pH, electrical conductivity, turbidity, apparent color, suspended solids, nitrate-N, ammonium-N, phosphorus, potassium, calcium, magnesium, sodium, boron, iron, manganese, copper, zinc, nickel, aluminum, arsenic, barium, cadmium, chromium, and lead. Results indicate that runoff from all green roofs is higher than the average pH of incoming acid rain water, although the pH of runoff from the rooftop farm was slightly lower than that of the extensive green roofs. The conductivity, apparent color, and suspended solids concentrations of runoff from the rooftop farm were higher than those of the extensive green roofs, but not higher than values reported in the literature on agricultural runoff. The concentrations of nitrate-N, phosphorus, potassium, calcium, and magnesium in runoff from the rooftop farm were also higher than those of runoff from the extensive green roofs. Measured values of nitrate-N, calcium, and magnesium were not higher than concentrations reported elsewhere in the green roof literature or in agricultural literature; nor where they higher than EPA guidelines for water quality. Measured values of phosphorus and potassium were found to be higher than EPA guidelines. However, changes in nutrient management practices would help reduce these values.

1. Introduction

Green roofs have been shown to have a wide number of benefits including reduced air and noise pollution, increased habitat and biodiversity, increased roof lifespan, stormwater retention, energy savings, and mitigation of the urban heat island effect (Alexandri and Jones, 2008; Barrio, 1998; Carter and Jackson, 2007; Getter and Rowe, 2006; Getter et al., 2007; Loder and Peck, 2004; Rowe, 2011; Saiz et al., 2006; VanWoert et al., 2005; Wong et al., 2003). Thanks to an increasing number of rooftop farms and gardens (Greenroofs.com, 2014), food production can be added to this list of benefits. Although rooftop agriculture may solve some of the problems inherent in ground level urban agriculture, such as limited space availability, it presents its own set of challenges (Whittinghill and Rowe, 2012). One of these challenges is a greater requirement for inputs, such as irrigation water and fertilizers, than in-ground urban agriculture, which could impact the stormwater performance of the green roofs (Whittinghill and Rowe, 2012). The ability to retain stormwater and improve stormwater quality is one of the major environmental benefits of green roofs (e.g. Berghage et al., 2009; Emilsson et al., 2007; Rowe, 2011). To date, little research has been done on the impact of farming practices on the ability of a green roof to mitigate stormwater management issues. This is especially important when considering the differences in nutrient

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http://dx.doi.org/10.1016/j.ecoleng.2016.01.047
0925-8574/

management practices between ornamental green roofs, and those used in agricultural production.

Conventional green roofs can improve on the quality of runoff water compared with non-vegetated roofs (e.g. Czemiel Berndtsson, 2010). There are many factors which affect the runoff quality of a green roof. These include environmental factors, such as the size of rain events (Czemiel Berndtsson et al., 2006; Teemusk and Mander, 2007), the amount of atmospheric deposition taking place (Alsup et al., 2011), and the presence of acid rain (Berghage et al., 2009; Bliss et al., 2009). Green roof characteristics also impact runoff water quality. Construction of the roof and drain pipes (Alsup et al., 2011; Czemiel Berndtsson et al., 2006) and the substrate used are particularly important. Substrate composition (Alsup et al., 2010; Czemiel Berndtsson, 2010), compost content (Hathaway et al., 2008), and depth (Czemiel Berndtsson, 2010) all affect runoff quality. The presence of plants (Alsup et al., 2010), plant type (Czemiel Berndtsson, 2010; Dunnett et al., 2008; Monterusso et al., 2004), rooftop maintenance practices such as fertilizer use (Czemiel Berndtsson, 2010; Emilsson et al., 2007), and age of the green roof (Czemiel Berndtsson, 2010; Czemiel Berndtsson et al., 2006; Hathaway et al., 2008; Köhler et al., 2002; Teemusk and Mander, 2007; Van Seters et al., 2009) also affect runoff water quality. Combined, these factors determine if a particular green roofs acts as a source or a sink for nutrients and heavy metals. Green roofs are generally considered to reduce runoff heavy metal concentrations compared with other urban surfaces (Czemiel Berndtsson, 2010; Czemiel Berndtsson et al., 2006; Rowe, 2011), but results for nutrients, such as nitrogen and phosphorus are mixed (e.g. Czemiel Berndtsson et al., 2006; Hathaway et al., 2008).

Substrate composition, compost content, and depth, and fertilizer use are likely to differ when comparing conventional green roofs to agricultural green roofs. Agricultural rooftops are likely to use substrates with higher organic matter or compost content than conventional green roofs, to help supply nutrients to the crop plants. They are also likely to use deeper substrates to retain water and support the crop plants. The application of fertilizers to green roofs, even at the $5\,g\,N\,m^{-2}$ rate recommended for typical extensive green roofs (FLL, 2002), can have a negative impact on runoff water quality, especially if soluble fertilizers are used (Czemiel Berndtsson et al., 2006; Emilsson et al., 2007; Rowe, 2011; Rowe et al., 2006). It is expected that this impact would be increased if fertilizers were applied at the much higher rates of up to $22.3\,g\,N\,m^{-2}$ recommended for vegetable crops grown in soil (Warncke et al., 2004). Vegetables grown in green roof media, with low organic matter content and cation exchange capacity (Emilsson et al., 2007), might require rates of fertilizer application that are higher still. This implies that agricultural green roofs are liable to be a much higher source of nutrients than their ornamental counterparts, which could have negative environmental consequences.

Nutrients, especially nitrogen and phosphorus, in runoff water can lead to issues downstream from their source. The addition of nitrogen and phosphorus to surface water bodies can lead to eutrophication, which can lead to increase algae production and hypoxia due to larger amounts of organic matter decomposing, reducing the quality of water body for fish habitat, recreational activities, and drinking water (USEPA, 2003). This has historically been a problem in areas with large amounts of agricultural production that has led to the implementation of many best management practices to reduce nutrient losses from agricultural land in runoff (Osteen et al., 2012; USEPA, 2003). These practices touch on nutrient application rates, such as matching nutrient supply to crop needs through nutrient budgeting based on soil test results (Osteen et al., 2012; USEPA, 2003; Warncke et al., 2004), nutrient application methods, such as incorporation vs topdressing of nutrients, and nutrient application timing (USEPA, 2003). They also include practices to catch nutrients leaving agricultural areas before they enter surface water, such as the use of retention ponds, buffers, bioswales, and constructed wetlands (USEPA, 2003). The former group of practices could most easily be adapted to use on agricultural green roofs, but research has not yet been to determine what adaptations would be necessary to make them effective under the different conditions presented by rooftop agriculture.

There are other methods which could be adapted from both in ground agriculture and conventional green roofs to manage the tradeoff between plant nutrient requirements and runoff quality. Practices designed to limit irrigation needs would likely increase the green roofs water holding capacity, reducing runoff, and therefore the amount of nutrients being removed from agricultural rooftops during storms. The use of substrate moisture management practices such as mulch (e.g. Gruda, 2008; Monks et al., 1997) have been effective at limiting irrigation needs in in-ground agriculture and could easily be adapted to a rooftop setting. The collection and recycling of runoff for irrigation is another option. Reducing soil disturbance, by reducing tillage and the use of cover crops, reduce the amount of erosion that takes place, and therefore nutrient losses during runoff (e.g. Franklin et al., 2012; Tiessen et al., 2003; USEPA, 2003). These practices are also suited to use in rooftop agriculture. The effectiveness or practicality of many of these measures have not, however, been fully explored in agricultural rooftop settings. One prior study performed on test plots indicated that the effect of fertilizing a vegetable green roof would depend heavily on the amount of fertilizer applied and plant nutrient requirements (Whittinghill et al., 2014), but to date little research has been done on full scale green roof farms.

This study was designed to advance knowledge about the effects of rooftop agriculture on stormwater management issues by monitoring the runoff water quality from a full-scale, working roof top farm in Long Island City, Queens, and New York. The main objective of this study was to compare the runoff water quality of a full scale agricultural rooftop to that of conventional, extensive sedum green roofs. To that end, runoff water quality results from the rooftop farm were compared to those of a previous study of non-agricultural green roofs around New York City (Culligan et al., 2014), enabling examination of the impact farming has on runoff quality. It was expected that agricultural roofs and conventional green roofs would perform differently, because the rooftop farm has a higher substrate organic content and applies fertilizers at higher rates and with more frequency than is typical for conventional green roofs.

2. Methods

2.1. Site description

The rooftop monitoring took place at the Long Island City Brooklyn Grange (BKG) rooftop farm located at 37-18 Northern Boulevard in Queens, New York. The rooftop farm was installed in 2007 and uses Rooflite® green roof media (Skyland USA LLC, Landenberg, PA) mounded into rows with a depth of 20–25 cm (8–10 in.) and 2.5–5 cm (1–2 in.) between row depth. The farm covers almost all of the 3995 m^2 (43,000 ft^2) rooftop. Non-vegetated areas of the roof include stairwells, the central roof walkway made of gravel, and walkways between crop rows (Fig. 1a). The green roof is planted with vegetables, herbs and some flowers for cutting, including sunflowers. Irrigation is supplied to the plants through a drip irrigation line 3 times daily for 30–40 min, depending on weather conditions. Nutrients are supplied to the rooftop farm through the annual addition of about 2540 kg (5600 lb) of compost and the use of organic fertilizers and amendments. In 2012 these included 68 kg (150 lb) of alfalfa meal, 45 kg (100 lbs) of kelp meal, 136 kg (300 lbs) of Pro-Gro 5-4-3, and 68 kg (150 lbs) of sulfate of potash (North Country