Green Infrastructure: Experimental Assessment of Environmental & Economic Benefits in Urban Settings

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ABSTRACT

In urban environments, like Bridgeport CT, impervious cover (e.g. cements and asphalts, which cannot absorb rain water) is a larger portion of surface area, resulting in issues related to stormwater flooding and transporting of untreated pollutants into nearby waterbodies. Green infrastructure (GI; e.g. green roofs, rain gardens) provides an alternative means to reduce the amount of stormwater runoff, treating water at its source, and protecting soil and nearby water sources. But, how much runoff is treated by GI and how does GI handle stormwater pollutants, such as motor oils?

The goal of this project was to investigate: 1) how much water is captured by green roof modules and how much money a 1000 ft² green roof would save the city of Bridgeport in wastewater management per year and 2) how does GI manage/respond to hydrocarbon inputs from motor oil. To do this, I built a mock GI installation comprising four quadrants of green roof modules and applied different amounts of water and motor oil. I measured the volume of water retained by a green roof module and made a mathematical model on how much money Bridgeport would save in wastewater management a year with a 1000 ft² green roof. I also measured changes in pH and nitrates in the green roof soil and assessed influences of hydrocarbons on soil structure using scanning electron microscope.

I found that 1000 ft² of green roof cover could save the city of Bridgeport 57% of current wastewater management expenses per year. Additionally, I found that when hydrocarbons entered the green roof module they coated soil particles and did not come off with the removal of all moisture. However, I observed that hydrocarbons and nitrate levels were negatively correlated, suggesting hydrocarbon breakdown by microorganisms that require nitrogen as well.

INTRODUCTION

Background Information:

- On average, 43% of U.S. cities are covered by impervious surfaces (e.g. buildings, roads),[1] which do not allow stormwater to be absorbed into the ground.
- Non-absorbed stormwater travels across streets collecting contaminants—feces, oils, soaps, chemicals, rubbish, fertilizers, pesticides, and bacteria—a major source of water pollution.[2]
- Green infrastructure (e.g. green roofs, rain gardens; Fig. 1) uses vegetation and soils to reduce large stormwater flooding and treat the water at it's source.[3]
- On average, a green roof retains 25-40% (winter) to 70-90% (summer) of precipitation.[4]

Stormwater Runoff Causes[2]:

- Algae blooms in nearby water sources (fertilizers).
- Damage to organisms on all scales (toxic chemicals, oils, pesticides, phosphates).
- Soil structures become non-viable (nutrients are destroyed through chemicals).
- Biological contaminants such as feces pollute public recreational water fronts.
- Cities (e.g. Bridgeport, CT) spend over two millions dollars on stormwater treatment.[5]

Fig 1. UConn's first green roof, which was found to retain 51.4% of precipitation.

OBJECTIVES

Given the negative impacts of stormwater flooding and pollutants in urban areas, I investigated the benefits of green infrastructure (particularly green roof modules) in retaining stormwater and handling pollutants, such as motor oil. I investigated:

1. Water retention of green roof modules to model how much money the city of Bridgeport would save in wastewater management per year via a 1000 ft² green roof;
2. Responses of green roof modules soil chemistry and properties to hydrocarbons inputs from motor oil.

Fig 2. Building the experimental green roof modules. Four green roof modules were donated from Prides Corner Farm, and were placed into separate compartments that comprised drains to allow collection of non-retained water.

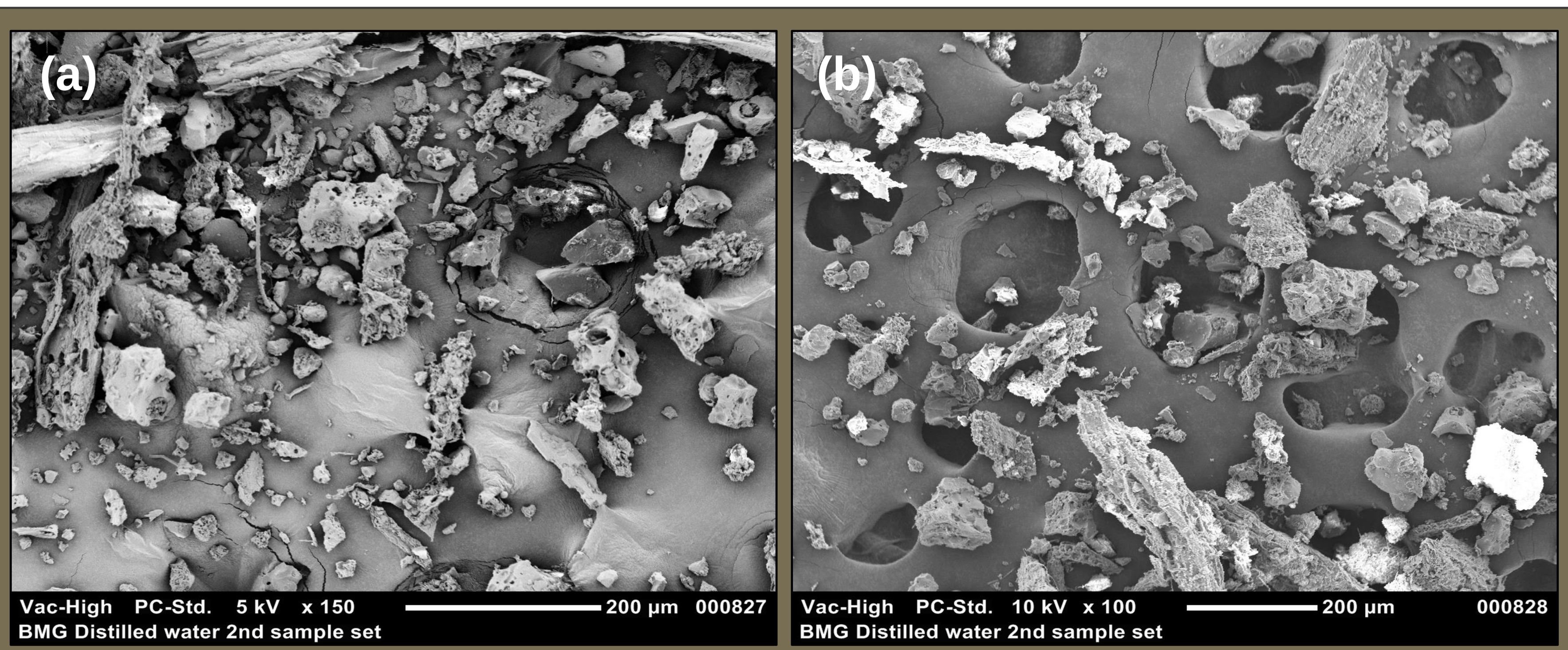

Fig 3. Scanning electron microscope (SEM) images of (a) control soil sample (water only applied) and (b) experimental soil sample (motor oil and water applied). The SEM needs a carbon layer in order to attach the samples, which causes the indentations seen in the photos. The SEM also needs a gold coating on the samples for it to be conductive. White areas indicate that not enough gold coating stuck, meaning the soils were coated with oil, as seen in (b).

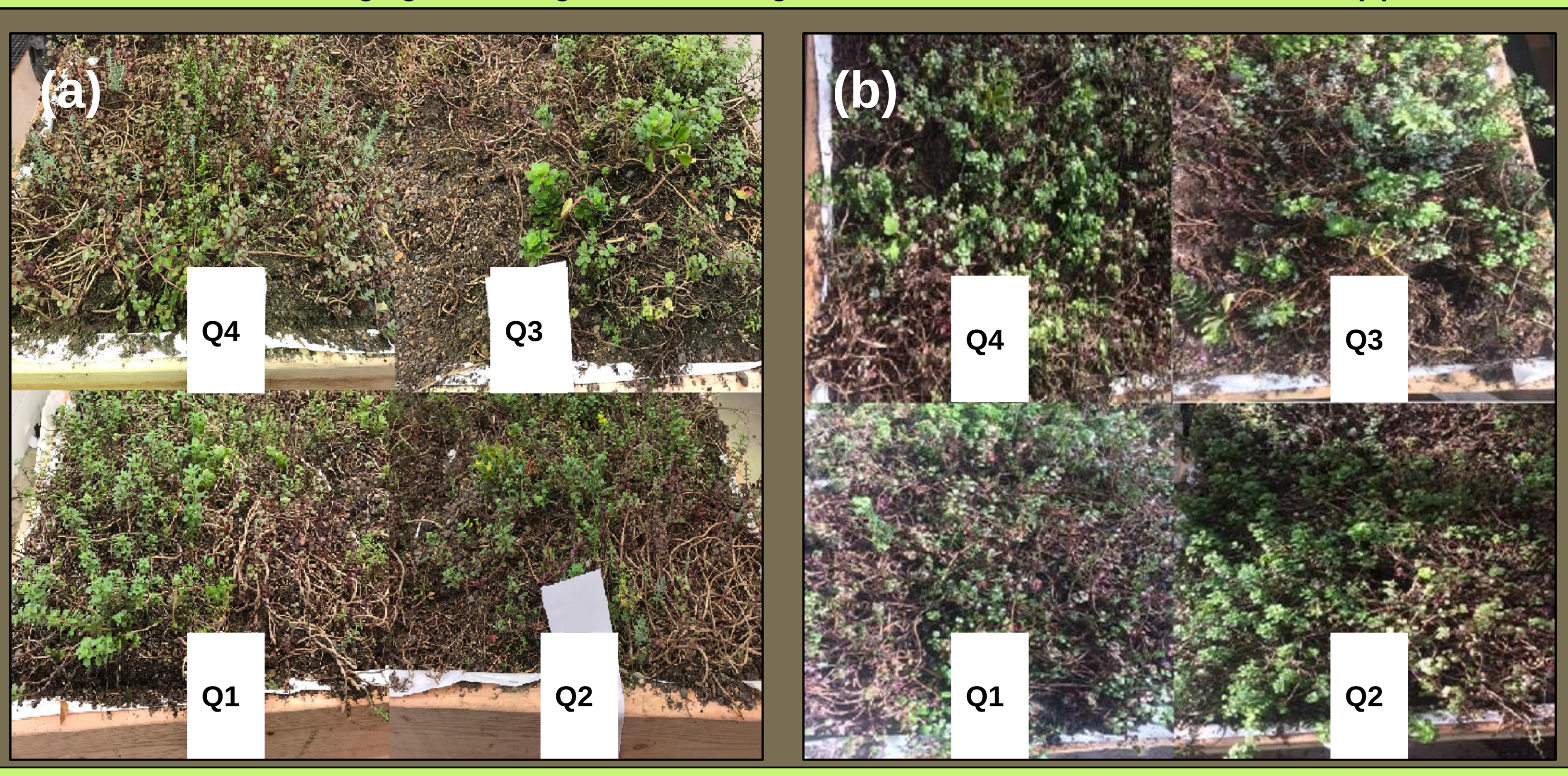

Fig 4. Condition of the sedum plants (a) pre trail and (b) post trial. In (a) & (b), control quadrants are Q1 & Q2, and experimental quadrants are Q3 & Q4. Growth can be seen post trial, especially in the controls; the control quadrants received five gallons of water while the experimental received one, which can be attributed to differences in growth.

METHODS

Experimental Setup

- Prepared four 2' x 4' quadrants green roof modules containing sand silt loam and sedum plants (modules donated by Prides Corner; http://www.pridescorner.com/).
- Created a 4' x 1' ½'' structure with dividers and four drains (Fig. 2).
- Two quadrants served as controls to compare the effects of the hydrocarbons from motor oil, as well as provide data on how much water the modules can retain (Fig. 4 Q1 & Q2).
- Two quadrants were used for experimental trials with diluted motor oil applied (Fig. 4 Q3 & Q4).

Data Collection & Procedure

- Pre-trial soil measurements: internal temperature, pH, nitrate, and ran soil sample under scanning electron microscope.
- Five gallons of tap water were applied to each control (Fig. 4 Q1 & Q2) within 8 minutes; drained water was subtracted from five gallons to determine how much water was retained.
- 300 ml of motor oil diluted into one gallon of tap water was applied to experimental quadrants (Fig. 4 Q3 & Q4).
- Post-trial soil measurements: internal temperature, pH, nitrate, and ran experimental soil sample under scanning electron microscope.
- The last three steps were repeated 4 times at 7-day intervals.

MODELLING ECONOMIC BENEFIT OF GI

- 2' x 4' sand silt loam green roof module retains an average 2.84 gallons of water (this study)
- 1000 ft² roof of impervious cover produces 623 gallons per 1 inch rainfall
- In Bridgeport, it costs about $0.0017 to decontaminate one gallon of water[6]

The following model depicts how much money is needed to treat runoff from a <u>1000 ft² impervious surface area</u>: $F(x)=623(x)(0.0017)$; x → inches rainfall

The following model depicts how much money is needed to treat runoff from a <u>1000 ft² GI unit</u>: $F(x)=(623-125*2.84)(x)(0.0017)$; x → inches rainfall, 125*2.84 → gallons retained by 1000 ft² GI unit

If x equaled 41 (e.g. average rainfall in New England/year) → 1000 ft² impervious cover would cost Bridgeport $43.42/year and 1000 ft² GI unit would cost $18.66/year, resulting in $24.76 saving.

GI SOIL CHEMISTRY & PROPERTIES RESPONSE TO HYDROCARBONS

Pre Vs. Post Soil Chemistry

- Steady decrease in nitrate levels as trials proceeded, which was negatively correlated with hydrocarbon amount (Fig. 5)
- Soil temperatures and pH levels in the experimental quadrants were not in response to the amount of motor oils (Table 1)

Hydrocarbon Interaction with Soil Particles

- SEM scans showed less gold coating on soil exposed to hydrocarbon inputs (Fig. 3), meaning oil remained attached to soil particles even after moisture removed.

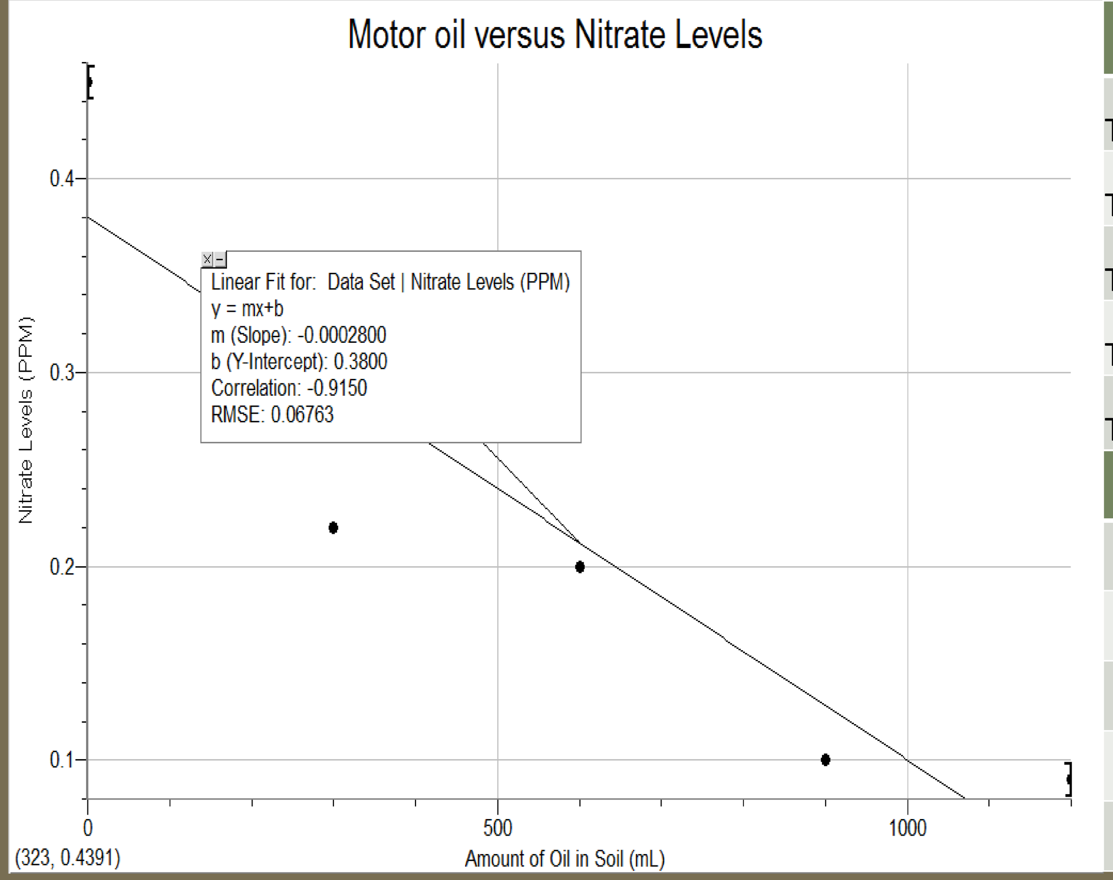

Fig 5. Correlation between amount of oil in the soil and nitrate levels of the soil; note the strong negative correlation. $R^2 = 0.8372$

Pre Trial Soil Temperature C°	Post Trial Soil Temperature C°
Trial - 19	Trial - 18.1
Trial 1- 22.1	Trial 1- 20.3
Trial 2- 20	Trial 2- 22.7
Trial 3- 21.0	Trial 3- 21
Trial 4- 21.4	Trial 4- 20.5
Pre Trial Soil pH	**Post Trial Soil pH**
Trial - 6.3	Trial - 6.1
Trial 1- 5.9	Trial 1- 5.8
Trial 2- 6.7	Trial 2- 6.4
Trial 3- 7.3	Trial 3- 7.3
Trial 4- 6.2	Trial 4- 6.1

Table 1. Depicts pre and post trial conditions for temperature (C°) and pH in the experimental quadrants.

CONCLUSIONS

Economic Benefits of GI

Sedum sand silt loam green roof modules retained on average 2.842 gallons of water per 2' x 4', which would save the city of Bridgeport 57% in wastewater management per year for every 1000 ft² of green roof modules. Bridgeport is the most developed city in CT. This means more GI units throughout the city could have major economic benefits.

Hydrocarbon (Oil) Effect on Microorganisms & Soil Properties

The internal temperatures and pH levels of the experimental quadrants remained constant (Table 1). As seen in Fig. 5, the nitrate levels of the experimental quadrants went down over time. While one possibility is that nitrifying bacteria were being compromised by the amount of oil in the soil, oil consuming microbes may have been responsible metabolizing the nitrates for energy. During the short term of the study, the oil remained in the soil (as seen Fig. 3b); knowing this, it would be interesting to monitor the nitrate levels to see if there are actually any microbes breaking down the oil. In this study unrealistically large amounts of oil were applied to magnify the long term affects of such conditions. It can be concluded that having oils drain into a GI structure would be a positive alternative as to having them drain into our waterways.

ACKNOWLEDGEMENTS

I would like to thank the following for their support throughout this project: Aris W. Stalis (community partner), Mr. Paul Trupp (Aquaculture shop teacher), and NRCA faculty. Thank you to Prides Corner Farms for the donation of green roof modules for the experiment. Finally, I would also like to express my gratitude toward Energize CT, United Illuminating, and EPA Soak Up the Rain for a generous scholarship that supported my participation in the NRCA.

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