Kansas State University

Evaluation of the Performance of the Memorial Stadium Green Infrastructure

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INTRODUCTION

Green roofs have been used by households for centuries, although perhaps in more primitive forms than today. Communities who first settled the plains capitalized on available thermal protection and provision from natural landscapes by building their homes into the sides of bluffs and other forms of ground cover before air conditioning was ever an option. More recently, corporations looking to invest in green initiatives, either for the sake of image or the environment, have been installing green infrastructure onto their buildings, predominately for aesthetic purposes.

In recent decades, the “green movement” has taken shape over much of North America. The focus of environmental quality has stretched from sustainable agriculture in rural America to using less water and harmful chemicals in cities. More specifically, innovators found a way to make this movement more visible and noticeable to general public. Green roof designs began to be constructed on buildings for rainfall recycling, thermal balance, and to bring “green” into city areas.

As green infrastructure becomes more popular and prominent in our society, it is necessary to understand what makes a system successful, and how to make it as efficient as possible. In this study, a green roof installed at Memorial Stadium on Kansas State University’s campus is assessed for its efficiency and appeal. To do this, several factors of this complex system were observed. This includes media type, plant type, irrigation, soil moisture, microbial community health, and aesthetic vigor.

LITERATURE REVIEW

Importance of Green Roof Media Selection

Introduction

Green infrastructure works to return urban environments to the ecological functionality that existed before urbanization (Palla et al. 2010). However, there are many restrictions that keep a green roof system from being able to mimic a natural system. This literature review first discusses the properties of a natural system that allow plants, microbial communities, and other species to survive. Then, basic guidelines that contractors must consider when building a green roof will be explained in order to understand the significance of climate and media type on these systems. The next section will summarize the compatibility between the green roof media and the native prairie plants growing in the Memorial Stadium system that is located in Manhattan, Kansas, USA. The successfulness of this system will be predicted. Suggestions for future research will conclude this review.

Properties of Natural Systems

“Be it deep or shallow, red or black, sand or clay, the soil is the link between the rock core of the earth and the living things on its surface. It is the foothold for the plants we grow”- Roy W. Simonson (USDA 1957). Soil is a fundamental living component of Earth’s systems. With it comes food, shelter for animals and microorganisms, stability for plants, and acts as a chamber for nutrients and gases that could otherwise be lost. Each service that soil provides adds to the network of processes, making soil an extremely complex topic. To understand the basic soil functions, one must learn the properties of soil that limit or continue processes.

Soil Formation

It has been known for many decades that soil is an ever changing foundation to the earth, commonly known as the skin to an apple. Similar to many systems in our environment, there are different "states" of soil conditions depending on changing properties within it. The smallest change in any one of the properties gives rise to a new soil, as shown in Eq (1). Each s represents

$$F(s_1, s_2, s_3, s_4, s_5, \ldots) = 0 \tag{1}$$

a property specific to the soil in question, such as nitrogen content, acidity, or clay content. Within each variable (s), are five factors: climate (*cl'*), parent material (*p*), biota (*o'*), topography (*r'*), and time (*t*). These factors are the independent variables that define the soil system (Jenny 1941). These factors influencing soil formation will determine the rates of physical and chemical

$$s = f\,(cl, p, o, r, t) \tag{2}$$

weathering, which in turn will decide the soil type and productivity. This poses limitations to plant growth and survival because soil must acquire, store, and deliver water to plants, which is dependent on soil texture (Zartman 2006). The Tallgrass Prairie of the Flint Hills is a large native prairie that extends from Marshall County, Kansas down into the northern part of Oklahoma. This area was once covered in shallow seas during the Permian Period, which laid limestone and chert. Overtime, some of the chert has weathered to leave behind a clayey soil (Nippert et al. 2012).

Water and Air Movement

In order to insure plant survival, there must be water and air at the appropriate times in the plant's life. This can be at a large scale, such as when the plant is just emerging or perhaps producing seed, or refer to a smaller scale on a day-to-day basis for daily functions, such as photosynthesis. In conjunction with climate, texture is the most important management factor controlling water in landscape aesthetics. Texture directly influences bulk density, porosity, and quantity and size of the pores in the soil, which controls water infiltration, water movement, and compaction.

Water-holding capacity is based on distribution of soil separates in a profile. Larger particles, such as sand (table 1), will form large capillaries in the soil known as macropores. Also, coarse soils have low surface area and hold little water directly on the soil surfaces. Therefore, water moves quickly through wet, coarse soils because large pores are able to conduct water more quickly than small pores. This does not only apply to water movement beneath the soil surface, but also includes higher infiltration rates and low runoff potential (Zartman 2006).

Size Limits of USDA Soil Separates	
Name of Separate	**Diameter Range (mm)**
Sand	2.0 – 0.05
Silt	0.05 – 0.002
Clay	< 0.002

Table 1. Particles are classified into different soil separates by size (USDA).

However, sand and silt are significantly larger than clay. There are large numbers of small pores within fine soils, creating less macropores and more micropores. Therefore, water moves very slowly through wet, fine soils due to small pore diameter. This slows infiltration into the soil and increase the chance of runoff (Zartman 2006).

In a study analyzing resistance to water movement in the rhizosphere, it was found that as a soil dries, large pores will drain excess water, resulting in an increasingly negative water potential. Also, a decreasing water content will result in a rapid increase in resistance to water movement. Bristow et al. (1984) found that this resistance to water movement was found to increase most rapidly in coarse soil (table 2).

Soil Texture	Total Available Water (in/ft of soil)	Bulk Density (g/cm^3)	Pore Space (%)
Sand	1.2	1.7	36
Sandy loam	1.5	1.5	43
Loam	2.0	1.4	47
Clay loam	2.3	1.35	49
Sandy clay	2.5	1.3	57
Clay	2.7	1.25	58

Table 2. This table from Zartman (2006) provides values for the properties of soils depending on different soil textures.

As noted above, native prairie soils are typically higher in clay content. Therefore, when a soil dries, macropores will drain. However, due to the high clay content, there are not many macropores as there would be in a sandier soil. Water can stay in the micropores and be released over time to the plant. This movement to the plant will typically happen with assistance of fungal hyphae. Fungal hyphae form a mutualistic relationship with plant roots so that the plant can receive phosphorus and water. These functions of a native prairie soil are fundamental to support tallgrass species.

Nutrient-holding Capacity

The five soil forming factors will determine the productivity of a soil. Productivity of a soil is the ability of a soil to support crop production or, in a native prairie, grass production determined by the entire spectrum of its physical, chemical, and biological attributes (Roy et al. 2006). Soil fertility is just a small component of this spectrum in order for plants to survive, they must acquire nutrients for physiological function.

Due to their negative charge, clay and organic matter regulate nutrient adsorption and release from soil solution. Clay's interactions with nutrients is known as the cation exchange capacity. A soil higher in clay will have a higher nutrient-holding capacity compared to a sandy soil. Organic matter is a complex substance that forms from decaying plant tissue. Organic matter holds nutrients until microbes begin decomposition and excretion of those nutrients for plant uptake (Brady and Weil 1999).

In a native prairie system, grasses produce deep and complex root systems that have a large turnover rate. Plant matter is constantly recycled, providing carbohydrates to microorganisms that decompose organic matter and release nutrients for plants. Soil organic matter is very fertile and is the main reason prairie systems continue to exist. An abundance of organic matter and clay allows the nutrients to be stored on the soil surface and later extracted by plant roots. The large amount organic matter in native grasslands provides a highly productive system with a high nutrient holding capacity.

Plant Species

Plants of different species survive in different climates due to adaptation to temperature, precipitation, nutrient availability, and competition. These factors affect diversity of a community in a given ecosystem, which can impact the successfulness of an ecosystem.

The Tallgrass Prairie systems are dominantly C_4 plant species that create a complex root system. However, native prairie systems are very diverse, providing many benefits that sustain the system. Legumes, C_3 plants, fix nitrogen that feed itself and eventually other organisms. Root systems of C_4 plants are often very dense and are able to reach nutrients that otherwise would be unavailable. Other grasses in the prairie have deep tap roots that, during a drought, will provide water to the system by bringing water into the surface soil from deeper in the profile. This is especially important on the uplands of the prairie where the soil is deep, but water has drained towards the lowlands. However, these deep roots only have significance when resource availability is limited in surface soils. Research conducted at the Konza Prairie Biological station have shown that 42% of the total root length is in the top ten centimeters of the soil. There is little reliance on roots that are deeper than 30 centimeters (Nippert et al. 2012).

Green Roof Systems

Choosing the media of a green roof is one of the most important decisions of the design process. The media must take on a role of an artificial soil for plant growth and must provide moisture, nutrients, and physical support while being lightweight, chemically stable, aeratable, and able to freely drain water (Young et al. 2014).

Restrictions for Green Roofs

Media selection must meet certain requirements so that the green roof system does not fail. Failure to choose the correct media can lead to plant death, decreased water-use efficiency, erosion, or even roof collapse due to weight of the material.

Weight

The weight restrictions of a desired location for a green roof can alone be the deciding factor for the media type used. This depends on the structural stability of the location the green roof will be constructed. There are select materials that are commonly used in green roof systems that are too heavy for certain roofs, especially when plants and water are added to the system.

Base Materials	**lbs/ft^3**	**kg/m^3**
Gravel, loose, dry	95	1522
Gravel, with sand, natural	120	1922
Gravel, dry 1/4 to 2 inch	105	1682
Gravel, wet 1/4 to 2 inch	125	2002
Sand, wet	120	1922
Sand, wet, packed	130	2082
Sand, dry	100	1602
Sand, loose	90	1442
Sand, water filled	120	1922
Sand with Gravel, dry	103	1650
Sand with Gravel, wet	126	2020
Brick, common red	120	1922
Brick, fire clay	150	2403
Brick, silica	128	2050
Brick, chrome	175	2803

Table 3. Above is a table of densities of different types of base green roof materials (Walker 2016).

Other common media used in green roof systems include bricks, fiber, clay materials, loam, compost, vermiculite, perlite, and coco-peat (Razzaghmanesh et al. 2014; Vijayaraghavan and Raja 2014). Many corporations have started to develop their own media mixes. Most include a mixture of different materials since each material has a specific purpose that benefits the system. These functions include nutrient-holding capacity, absorption of heavy metals that may be in stormwater, and water-holding capacity.

In relation to the weight of the material, there are restrictions to how much water the media can hold so that the combination of water, plants, and media are not too heavy. As shown in figure 3, wet material is much heavier than dry material. This relates to the media's water-holding capacity. If the media were mostly composed of dense or clayey materials, the system would hold too much water and pose stress on the structure.

Plant Species

When choosing a media type, plant species can become a restriction due to nutrient and water needs. Plants selected for green roof systems must be able to tolerate increased wind velocities, sun exposure, extreme heat, drought conditions, and shallow root depths. It is important to select suitable plants for green roofs according to the local climate conditions (Razzaghmanesh et al. 2014). In a green roof system, unlike a natural system, it is important that plants do not grow too large. In that case, the media needs to control growth so that the plants live longer and there won't be too much weight on the roof (Berretta et al. 2014). Plant species that naturally occur in dry conditions are more suited to a green roof environment (Graceson et al. 2014). This is especially true in areas with low rainfall where irrigation would be necessary to sustain the system. Therefore, plants with more leaf succulence often show higher survival rates. Crassulacean acid metabolism (CAM) plants have the highest water-use efficiency of the three photosynthetic pathways. In that case, plants like C. rossi are very successful in green roof systems (Razzaghmanesh et al. 2014).

Summary

Building a green roof system to mimic a natural system can be very complicated in order to ensure survival. Understanding water and plant relationship is essential for sustainable green roof development. In a study to determine the survival of green roofs in a dry climate, plants had better yield in the intensive, deeper systems (Razzaghmanesh et al. 2014). This is also true in the Tallgrass prairie where deep soils are common. However, in the Memorial Stadium green roof, irrigation is often and nutrients are supplied. In that case, after studying Dr. Nippert's research (2012) it can be assumed that grass species in the Memorial Stadium green roof will not need deep roots to reach for nutrients or water.

After analyzing substrate characteristics of the Memorial Stadium green roof and comparing them to both the native Tallgrass Prairie and other green roof systems, it can be noted that the Memorial Stadium green roof is much different than others. The native Tallgrass Prairie is high in clay, unlike the Memorial Stadium green roof system that is majority sand. However, the success of the system will ultimately depend upon the water and nutrients that will be available to the native grasses since the plants usually only develop deep roots under stressed conditions. Also, different range grasses prefer different soil textures, so adaptation to the system's media could occur (Anderson et al. 2006).

Impact of Microbial Community

Introduction

A major determinant of soil health is the microbial community and activities of such microbes concentrated in the soil. Microbes are impacted by media type, moisture content, soil pH, temperature, and management of the soil, amongst other environmental factors (Lange Markus et al. 2014). "A single teaspoon (1 gram) of rich garden soil can hold up to one billion bacteria, several yards of fungal filaments, several thousand protozoa, and scores of nematodes" (Herring 2016). Hence, microbes play a vital role in soil quality and nutrient cycling that combine with other factors to create a healthy and sustainable plant population (Melissa A. Cregger, et al. 2012). However, there is very little current research on microorganisms and their role in green roof substrates.

The site under consideration is located on Kansas State University in Manhattan, Kansas. A green roof was installed on an old stadium seating structure, being such there are two sides; one facing West, consisting of a diverse array of mostly native shrubby material, and the other facing East, consisting of mostly native tall grasses and prairie shrubs. The media chosen is primarily sand, and is housed in a porous honeycomb grid due to the existing structure being on such a steep grade. The goal of this review is to analyze factors affecting soil microbial populations and understand the benefits of a healthy microbial community in green roofs to construct a plan to use microbes to maximize the water and energy use balance at memorial stadium.

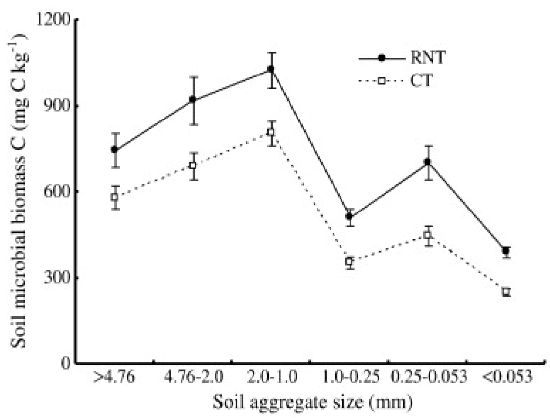
Factors Affecting Soil Microbial Populations

Moisture, Temperature and PH

Research shows that moisture is a primary factor affecting microbial biomass (Lange, Markus, et al. 2014). Soil moisture content is determined by the climate, seasonal variability, bulk density of soil, and soil texture among other factors. A study by the University of British Columbia examined soil moisture as the major factor influencing microbial community across seven biogeoclimatic zones in Canada. Through Phospholipid fatty acid analysis (PLFA), this study found that "soil moisture was significantly positively correlated with total microbial biomass and with *all* bacterial PLFA signatures" (Brockett et al. 2012); indicating that all types of microorganisms increased based off of specific PLFA profiles. In addition, they concluded that "Soil moisture (%) was significantly negatively correlated with the potential activities of enzymes which degrade lignocellulose, along with the chitin-degrading enzyme beta-1,4-N-acetylgluco- saminidase (NAGase), and the labile C-degrading enzyme beta-1,4- glucosidase" (Brockett et al. 2012). These results indicate that soil moisture is not only important in raising microbial biomass, but also had an effect on soil enzymatic activates that are involved with organic matter turnover; an important factor in plant health. Another study conducted in grasslands of china showed a positive relationship between interannual precipitation and microbial respiration and biomass. (Liu et al. 2009) indicating microbial population variability between seasons. The study also revealed a relationship between increased air temperatures that in turn increases surface evapotranspiration and reduces soil moisture availability, negatively affecting plant growth and microbial root activity.

Media Type and Depth

Soil texture is primarily described in relation to the percent of clay, silt, and sand in the sample. There are 12 soil classifications based on these ratios, with variable interactions between nutrients and the microbial community (Molineux et al. 2014). Microorganisms in soil live in water-filled pores and at surfaces (Gupta et al. 2015). As displayed in Figures 1 and Figure 2, the highest levels of microbial biomass carbon and soil respiration have been found to be associated with aggregates of 1-2mm in size (Jiang, X., et al. 2011). Different media types govern the soils ability to retain nutrients through their cation exchange capacity, and affect soil aggregate formation, therefore affecting how and where microbes may colonize. Solera et. al. describes factors that influence soil aggregation; "Clay content and mineralogy- through the forces of attraction and cohesion between them and microorganisms- joining the particles by adsorption mechanisms, secreting slime and wrapping product particles, and indirectly through their role in organic matter dynamics"(Mataix-Solera et al. 2011). In addition, the depth of substrate is a governing factor of what type of bacteria can colonize, and to what ratio bacteria and fungi persist (Molineux et al. 2014) as shown in figure 3. Further research is needed to understand the complex interactions between substrate type and depth because studies show variable results due to high variability in climate, soil pH, and complex interactions between different bacterial families and fungal types.



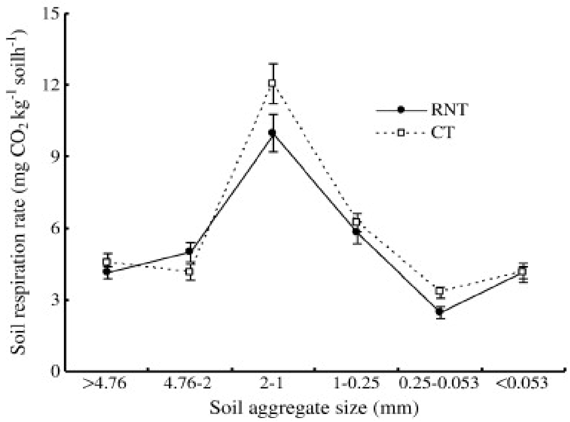
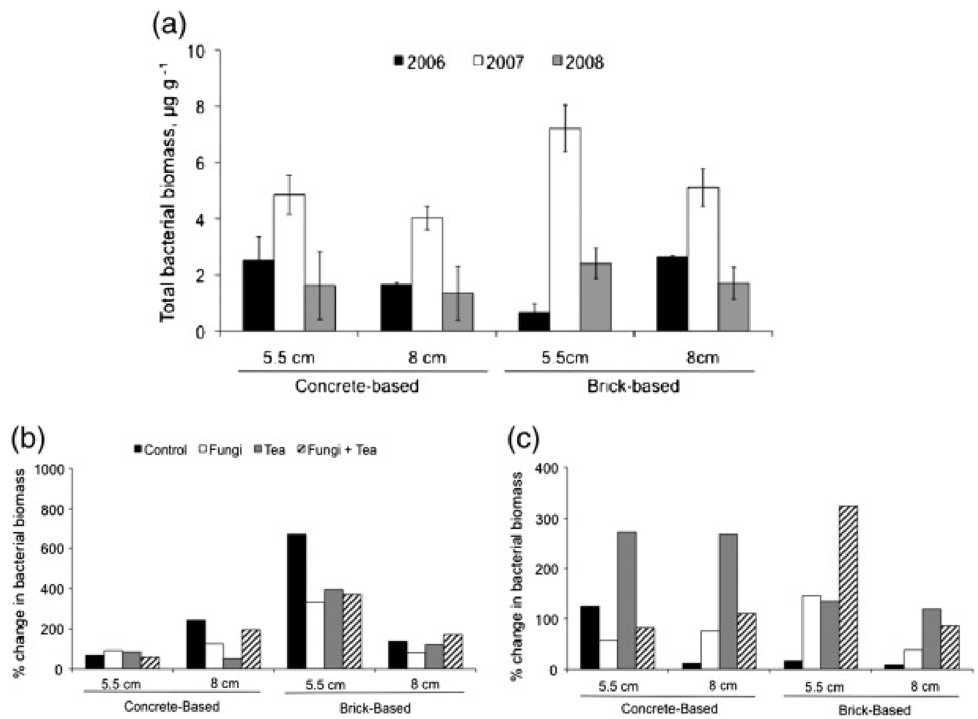


Figure 1: Soil microbial biomass C associated with different sizes of aggregate under RNT and CT (RNT, combines ridge with no-tillage; CT, conventional tillage). Jiang, X., et al. 2011

Figure 2: Soil respiration (CO_2 production) associated with different sizes of aggregate under RNT and CT (RNT, combines ridge with no-tillage; CT, conventional tillage). Jiang, X., et al. 2011



Plant Community

Figure 3: (a) Total bacterial biomass in two substrate types (concrete-based and brick-based) at two depths (5.5 and 8 cm) over 3 years. Bars represent means ± standard error.

Percentage change in total bacterial biomass from 2006 to (b) 2007, after treatments and (c) 2008, 1 year after treatments applied. Molineux et al. 2014

Soil microbial community is closely linked to plant communities through complex interactions. A review by notorious soil microbiologists, Gupta and Germida explains, “Plants affect the soil microbial community through biomass production, litter quality, seasonal variability of litter production, root-shoot carbon allocation and root exudates” (Gupta et al. 2015). It has been suggested that plant communities providing litter with high C:N ratio favor decomposition by fungi, whereas plant communities producing litter with low C:N ratio favor decomposition by bacteria (Brockett et al. 2012). This is because fungi are more efficient in carbon metabolic activity, suggesting that a higher fungi:bacteria ratio may indicate a more productive and healthy soil system. A study in Sevilleta Wildlife National Refuge in New Mexico shows that season, treatment, and tree type all had strong individual effects on the ratio of fungi to bacteria (Melissa A. Cregger, et al. 2012).

Land Use Management

Agricultural processes have shown to have a negative effect on soil nutrient content (Jiang, X., et al. 2011). Tillage disrupts soil aggregates, decreases total soil organic carbon, decrease cation exchange capacity, and increases erosion. (Jiang, X., et al. 2011). Fields that produce high residual residue and burning of tallgrass prairie can have positive effects on soil microbial health. (Steenwerth et al. 2002, Jiang, X., et al. 2011). The carbon inputs provided by excess residue (dead organic matter), in addition to soil warming and reduced competition provided by burning, allow for an active microbial community with higher rates of organic matter turnover (Mataix-Solera et al. 2011).

Benefits of A Healthy Microbial Population

Soil Aggregate Stability

Having a healthy microbial community along with proper media will help form and stabilize soil aggregates (Gupta et al. 2015). Having a moderately sized and stable aggregate will prevent excess leaching, erosion, and water runoff by increasing the capacity of the soil to hold onto nutrients and increase water pore space (Falsone et al. 2016). If the soil is able retain the nutrients provided, there is less need for fertilizer application and excess irrigation may be avoided as well. As the soil remains undisturbed and inputs remain plentiful and consistent, microbial and soil aggregate interaction will enable a more sustainable and active green roof.

Nutrient Cycling, Decomposition, and Carbon Sequestration

The microbial community in soil is primarily responsible for the decomposition and cycling of nutrients necessary for overall plant and environmental health. A healthy microbial community will provide for rapid cycling components that account for a major proportion of nitrogen and phosphorus taken up by plants. (Coleman et al. 1983). There is also continued research being conducted by the Agricultural Research Services in regards to offsetting carbon emissions by sequestering additional amounts of carbon in soils and vegetation, which microorganisms play a key role (USDA, 2016).

Energy Production

New methods are being developed that allow us to harvest energy produced through microbe and plant interactions. Plant-Microbial fuel cells (PMFC) are a method under development and are of special interest in green roof systems. A PMFC functions through plant roots fueling electrochemically active bacteria at the anode by excreting rhizodeposits. Rhizodeposoits are the organic material excreted by plant roots and accounts for 20-40% of the plants photosynthetic productivity (Strik et al. 2011). These organic compounds are broken down by a mixture of microorganisms that are connected to anodes and cathodes within the soil, generating constant energy flow to a power harvester. The basic system of such Microbial Solar Cells is diagramed in Figure 4. The first study of this system shows the potential to generate 21 GJ $ha^{-1}yr^{-1}$ (67 mW/m^2) (Strik et al. 2011).

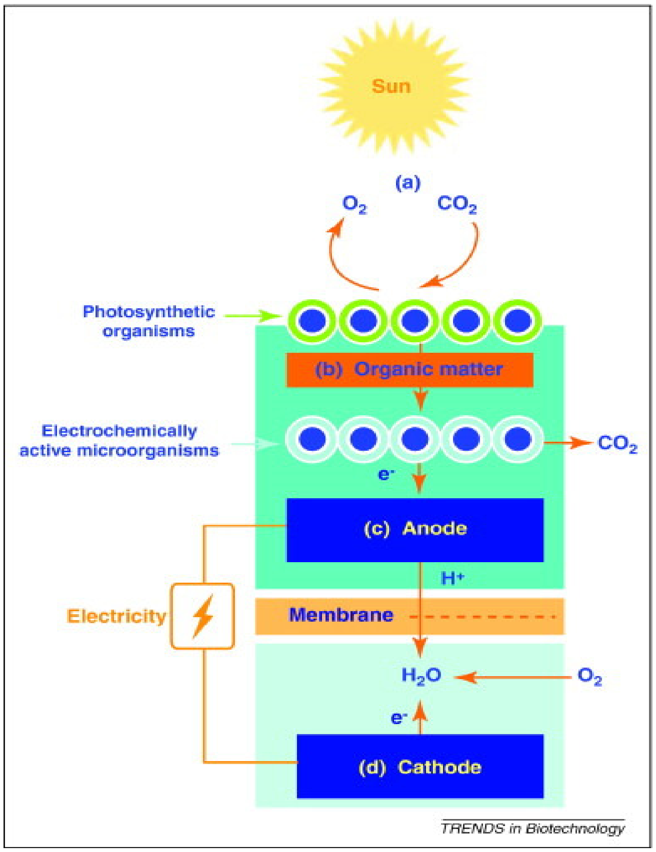


Figure 4: Model of a microbial solar cell including the basic principles. **(a)** Photosynthesis ($6CO_2+6H_2O \rightarrow C_6H_{12}O_6+6O_2$). **(b)** Transport of organic matter to the anode compartment. **(c)** Anodic oxidation of organic matter by electrochemically active bacteria (e.g. $C_6H_{12}O_6+12H_2O \rightarrow 6HCO_3^-+30H^++24e^-$). **(d)** Cathodic reduction of oxygen to water ($6O_2+24H^++24e^- \rightarrow 12H_2O$). (Strik et al. 2011).

Summary

In an exploration of the current literature pertaining to the importance of microorganisms in soil, it is apparent that there are a multitude of equally significant factors that work in unison to support a healthy plant population. Proximal factors, such as soil moisture, temperature, pH, and organic matter content combine with site factors such as regional climate, parent material- soil texture, depth and mineralogy, and plant diversity all affect the microbial community (Lange, Markus, et al. 2014). While there is very little research specifically on microbial populations within green roof systems, this information has provided a solid base to construct a viable plan for microbial integration into green roof systems and why microbes are a significant factor in a sustainable system.

The green roof implemented at Kansas State University's Memorial stadium is intended to be a staple of the Konza prairie on the KSU campus, housing native tall grasses and prairie shrubs. However, the media selected is primarily sand, reportedly >60% according to Turf and Soils Diagnostics (Sharp, 2015). It is also only 4-6 inches deep in most areas in addition to the dead organic matter being removed annually. All of which, as indicated by this review, may have adverse long-term effects on the sustainable nature of the green roof. In contrast, the native soil at Konza prairie is a silty clay loam that can reach as deep at 2m and has natural inputs as well as burning and grazing acting upon the soil (KSU, 2015).

While the memorial stadium site has not been set up for optimum productivity or ideal material for support of healthy and native microbial populations, there are steps that can be done to increase microbial population and productivity. A study examined how inoculants such as “compost teas” may act as a way of applying “live” microbes to soil (Molineux et al. 2014). Results showed an increase in biomass in experimental plots within a year of inoculation. This study also indicated that these populations are sustainable, with no need for additional compost tea treatments. This provides a viable option that may lead to reduced water and fertilizer needs for the memorial stadium green roof.

In summation, green roofs are often harsh environments that would benefit from the activities associated with microbial communities in natural soils. If a healthy rhizosphere is achieved then green roofs may be more resilient to harsh conditions in hot, dry months. “This would result in greener roofs over summer periods, sustaining benefits to other ecosystem services such as evapotranspiration (urban heat island effect), building cooling and water attenuation” (Molineux et al. 2014). While it is easy to overlook microorganisms, the benefits identified here in this review make it well worthwhile to take a closer look and identify the true potential of soil.

Water-Energy Balance

Introduction

While the construction of green roofs has become more popular, much of the research being done on green roof performance, specifically regarding water balance and ecologic impact, has been inconclusive. The research conducted thus far has demonstrated the complexity of green roof analysis given the plethora of both controlled and uncontrolled variables to be considered. This review will summarize what is known about each of these variables to analyze the water-energy balance of the green roofs at Memorial Stadium in Manhattan, KS given the parameters of these structures.

The factors that impact runoff quality and quantity will be considered, as well as the current understanding of irrigation impact and, as a sub-factor of that, biodiversity.

Runoff Quantity

The quantity of runoff from a green roof can be analyzed in terms of detention and retention. Per Stovin, et. al. (2015), retention is the rainfall held within the roof system without becoming runoff and detention is water temporarily held within the system before flowing off as runoff. Factors that specifically impact the retention capacity of a green roof include type of substrate, depth of substrate, vegetation type, slope and saturation (Bonoli, Conte, Maglionico, & Stojkov, 2013). The runoff quantity is also deeply impacted by the climate as this will affect the type of rainfall events that the green roof will be expected to manage, the relative humidity and the seasonal behavior.

Retention

Studies conducted have found that retention is greater for roofs with vegetation rather than without. This is likely due to root uptake, as well as the increase in complexity of the substrate layer due to the root system. It was also determined that the most effective vegetation for retention between sedum and meadow flower is sedum over meadow flower (Stovin et al., 2015). While vegetation factors into retention, it was found that the physical properties of the substrate and depth of substrate play a more significant role overall. Specifically, the pore size distribution, both inter-particle and intra-particle, was determined as a main factor in retention as the greater allowable space in the substrate increased retention (Graceson, Hare, Monaghan, & Hall, 2013). Growing media depth also logically increases retention as the water percolates and is stored at greater depths. The water holding capacity also increases as the roof ages and the organic matter and pore spaces increases (Berndtsson, 2010). Once the retention of the substrate is determined, it is less variable in comparison to detention since the substrate is unable to further store water once it has reached capacity. Most studies bring the substrate to field capacity before conducting tests on detention.

Detention

Detention includes “the detention due to plants; delays experienced as the runoff flows vertically downwards through the substrate; and interactions between plant roots and the substrate” (Stovin et al., 2015). Slope was found to not directly impact the hydrologic behavior of a green roof and therefore any degree of horizontal movement through the substrate is considered negligible. However, the time it takes for water to move vertically through the soil does impact the detention capacity of the water as this process delays the time for runoff to begin to enter the stormwater system. The peak runoff is delayed and the time for discharge to be completed is extended. This is can be observed in the figure below.

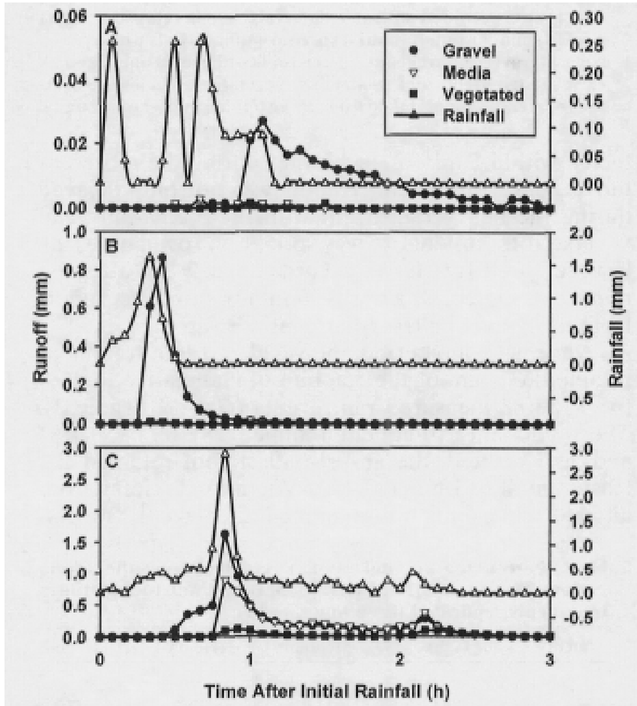


Figure 5. Runoff hydrographs of selected representative (A) light, (B) medium, and (C) heavy rain events recorded at 5-min intervals. Lines represent either rainfall (mm) or runoff (mm) from conventional roofs with a gravel ballast (gravel), non-vegetated green roofs with media only (media), or vegetated green roof treatments (vegetated) (VanWoert, D Bradley Rowe, Andresen, Rugh, & et al, 2005).

This figure not only demonstrates the ability of a green roof to slow down runoff, but also how much vegetation can additionally decrease runoff. Another interesting graphical representation of this is provided in Figure 2; this figure predominantly looks at the difference between impervious and green roof flows.

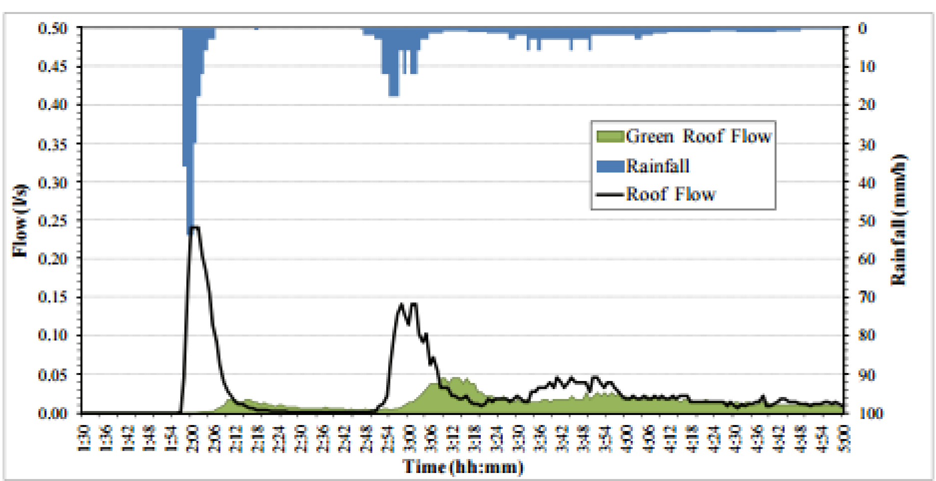


Figure 6. Monitoring results for rainfall event on 8/20/2013 comparing impervious roof and green roof flows (Bonoli, Conte, Maglionico, & Stojkov, 2013).

Climate

A study conducted in 2015 on a green roof in Missouri determined a water balance equation that considers runoff volumetric data, meteorological data and media properties to predict the quantity of stormwater runoff.
W_i is the water content of media on day I, K_c is the crop coefficient, P is precipitation, A is the surface area of the green roof and ET is the predicted evapotranspiration (Harper, Limmer, Showalter, & Burken, 2015). This model is particularly useful because of its consideration of external environmental factors as well as the green roofs design in analyzing performance.

Rainfall events

The size and intensity of rainfall events greatly impacts the retention and detention capacity of the green roofs. The more intense a rainfall event the less detention capabilities the green roof will demonstrate. When the roof is inundated with rainfall after it has already reached its water holding capacity, the substrate and vegetation is unable to slow down the water as much as the mobilization of the higher quantity of water is harder to slow down (VanWoert et. al., 2005).

Relative humidity

Humidity is an important factor for evapotranspiration (ET), the movement of water from the soil back into the atmosphere. The level of humidity is variable based on the climate of the location therefore it can have a large effect on the water balance of a green roof in some areas and a lesser impact in others. In climates with higher relative humidity, ET must be considered as another form of reducing runoff other than the retention capabilities of the roofs themselves. However, during the rain events themselves ET can be considered negligible. Additionally, in certain climates where the relative humidity isn't high, it can be considered negligible all together since higher temperatures correspond with higher relative humidity (Harper et al., 2015). The effects of humidity may also vary seasonally. Therefore, in regions where ET may be impactful in the summer months it might be negligible in the cold winters or vice versa (Graceson et al., 2013).

Runoff Quality

Water quality is defined by the difference between the source water to the runoff water in terms of nutrients, heavy metals and pH, since rain water is typically more acidic. The factors considered included type of material used, soil thickness, type of drainage, maintenance/chemicals used, type of vegetation, dynamics of precipitation, wind direction, local pollution sources and physicochemical properties of pollutants. A study conducted in 2010 found that while nutrient and heavy metal levels did not change to a statistically significant degree after moving through the substrate, the pH did increase (Berndtsson, 2010). Overall, green roofs do not have a significant impact on water quality (Berndtsson, Emilsson, & Bengtsson, 2006). However, if extensive use of nitrogen- or phosphorus-rich fertilizers are used, this will get into the runoff water and negatively impact the water quality. To counteract this, Berndtsson, Emilsson & Bengtsson (2006) suggest not using easily-dissolvable fertilizers as a preventative measure as well.

"First flush" phenomena

Typically, as nutrients, heavy metals and etc. are washed out of the green roof, a "first flush" phenomena is observed in which the initial release of contaminants to the runoff is high and then steeply decreases as time goes on. However, in the study conducted in Missouri a much slower release of total nitrogen (TN) was observed overtime (Harper et al., 2015). The release of total phosphorus is highly dependent on the type of substrate. It too did not exhibit as strong of a "first flush" phenomena as a typical flat roof does and it was released slowly overtime. The slower release is predominantly due to the presence of plant roots which stabilize the substrate and prevents erosion (Harper et al., 2015). This demonstrates the importance of substrate and vegetation selection for the sake of water quality. The greater the pore-size distribution of the soil the more room for water to be retained, including its contaminants. However, the dominant source of water quality maintenance is the root system. A well-integrated root system allows for a high degree of root uptake and therefore water quality improvement (Harper et al., 2015). Much of the results from the literature though are still variable in their findings amongst each other and even within their own tests.

Irrigation

Irrigation is predominantly considered to have a negative influence on the environment as a water is such a scarce yet valuable resources to sustaining life on this earth. Therefore, green roofs with irrigation requirements to maintain vegetation seems counterproductive to the general increase of environmental health. Additionally, since green roofs are typically installed to retain rainfall, it seems counterproductive to have artificial water needs. Overall, there are several advantages and disadvantages to installing water-dependent vegetation and several ways in which water overuse can be mitigating in irrigating these types of vegetation.

Advantages of water-dependent vegetation

Certain types of vegetation require a steadier intake of water than local climates can provide. Therefore, some green roofs, though predominately used to hold water, will need to be irrigated on a regular basis, especially in summer months. While vegetation such as sedum is typically used on green roofs because it can survive with minimal rainfall. However, more water-dependent plants such as prairie grasses are sometimes used, including at the Memorial Stadium green roofs. The main benefit of these types of vegetation is aesthetic appearance. A diverse array of grasses is much prettier to look at then sedum. Additionally, these water-dependent forms of vegetation provide for greater biodiversity. Especially as in the case of the stadium that uses grasses found on the prairie, such of the life that was once sustained in the area is once again able to find a home. Another direct benefit of a more consistent presence of water on the green roofs due to irrigation is thermal insulation. The heat capacity of water is much higher and therefore absorbs more heat from the sun that then transfers to the building. The cost of maintaining an irrigated roof can be less as well since fewer plants will die and need to be replanted. Cost will also be remediated by lower air-conditioning costs (Van Mechelen, Dutoit, & Hermy, 2015).

While water use maybe higher in irrigating green roofs, the benefits of aesthetic appearance, biodiversity and thermal insulation are all factors to consider as well. Additionally, current green roof irrigation practices are being improved to use less water more effectively. These include using grey water captured from storms either off the green roofs or off nearby buildings and advancing water level reading technology so that the soil is only irrigated if it needs it.

Summary

Natural grasses, irrigation, and high slopes are uncommon for green roof construction currently, however some research has been conducted that is relevant to the green roofs at Memorial Stadium. Natural grasses are more likely to require irrigation; however, they will also provide for greater biodiversity. Irrigation has more positive impacts such as thermal insulation and saved costs, though it still uses more water. There are tests being done to measure the water-balance of the roofs in their performance during rain events as well. It was determined that the effect of slope on runoff is insignificant as vertical percolation is dominant. Overall, green roofs slow down the runoff process by delaying peak release and lengthy discharge time from the roof. The quality of the runoff leaving green roofs compared to flat roofs was found to be less acidic, but otherwise unaffected unless an abundance of fertilizer was used.

Aesthetic Performance

Introduction

While it is important to investigate the science of the systems and processes that occur within the green infrastructure at memorial stadium, it is equally important to understand the scientific impacts that green infrastructure has on people and the surrounding community. This literature review investigates the external impacts green infrastructure has on people's health and wellbeing. When looking at the water energy balance of green infrastructure, such as the green roofs over memorial stadium, external impacts on people's health and wellbeing must be considered. There are many services that are provided by green infrastructure that may go unrecognized that influence the water-energy balance and this literary review takes an in depth look at those benefits. There are many benefits that we can receive from green infrastructure but I am only going to go to take and in depth look is the psychological, physical, and social benefits, or the ones regarding human health and wellbeing.

Psychological Benefits

Psychological benefits help improve mental health which is "…a state in which a person is most fulfilled, can make sense of their surroundings, feel in control, can cope with everyday demands and has purpose in life" (Coutts,C. 2015). Mental Health is very important, especially when it comes to college students. Students are expected to balance a variety mentally straining task in a vary pivotal transitional period from adolescence to adulthood. Mental health is paramount and the use of GI can positively affect not only the students, but also the teachers and surrounding community. The positive effects that GI has on mental health that are going to be explored is GI's ability to provide stress relief, increase positive affect, as well as its restorative properties.

Stress Relief

“Stress is a major issue for college students as they cope with academic, social, and personal challenges” (Bland,Helen W. 2012). “Stress can lead to myriad of different health related issues, from substance abuse to weight loss, weight gain, anxiety, depression, suicidal ideation among students, and an increased likelihood of physical illness” (Pedersen,Daphne E. 2012). GI’s ability to relieve stress is a huge benefit to the students as well as the faculty.

Multiple studies have been done that show a positive correlation between GI and reduced stress. A study that was conducted in Sweden that used questionnaires that were mailed to many participants showed statistically significant relationships between the reduction of stress and the amounts of visits to urban greenspaces. (Grahn, Patrik 2003). The other thing that is important with these results is that there was able look at the lifestyles of the large number of participants and rule that there were no effects of socio-economic status, gender, and lifestyle. Meaning that the use of greenspace was the only determinate perceived stress.

Another study that was carried out looked at the relationships between hair cortisol concentration, which is a biomarker used that can be used to measure chronic stress, and the amount of time spent in green spaces. They found “that living in neighborhoods with higher density of natural environment was associated lower levels of chronic stress” (Gidlow,Christopher J. 2016) However unlike Grahn’s results there was a correlation between area level income deprivation and higher levels of stress.

A different study looked at the blood pressure as indicator of stress for participants in a four-part experiment. There were two environments tested, both a natural and an urban environment, and two tests for each environment a walking and seated test. Before and after each experiment, the participants were given tasks, or stressors, and then by measuring blood pressure it was determined which participants were best able to handle the stress. They found that “the natural environment supported further blood pressure reduction, and the urban environment engendered further blood pressure increase” (Hartig,Terry 2003).

Through three different means of study it was found that natural environments, in various forms such contribute to the reduction of stress. This provides strong support for GI’s ability to reduce stress for everyone regardless of demographic, because even when correlations between income deprivation and stress are found, there are causal mechanism such as increased exposure to stress and decreased resiliency that contribute more in socioeconomic health inequities (Kristenson,M. 2004). It also gives students and faculty of Kansas State University a power and healthy tool to cope with stressful campus life.

Affect

Affect is positive emotions, self-esteem, and good feelings toward oneself or a situation. This is an important benefit because college students, as mentioned before, are going through a tough transitional period where they may not always feel good about themselves or where they are at. In 2008 43.2% of college students in the United States reported feeling so depressed that it was difficult to function at least once in the previous 12 months (Hill,Ryan M. 2015). Academic performance is also impaired with depression which hinders information processing and can lead to a student not able to complete their academic tasks (DeRoma,Virginia M. 2009). GI's ability to provide positive affect is an important benefit, that should be taken into consideration.

One study done used a mobile electroencephalography, or EEG, machine that measures different brain waves that can be used to interpret emotions. Participants wore this machine on three different walks through different parts of an urban area, the first walk was through a busy shopping district, a green space, and a high traffic commercial area. The subjects all walked the same route starting in the shopping district, then through the green space, and finishing in the commercial district. Using emotion recognizing software they were able to determine that across the board there was "a shift from more arousal, frustration, and engagement to meditation when transitioning to the green space and the opposite occurring when going from the green space to the commercial district" (Aspinall,Peter 2015). This giving support to GI's positive influence on affect.

Another study that was looking at perceptions of benefits of local parks was conducted via a telephone survey to 1305 people. Of the people who responded to the survey, the ones who frequented the parks had better perceptions about their health and happiness than people that did not use the parks (Godbey,Geoffrey 1993).

These studies also show positive correlation between GI or green spaces and positive affect. The presence of nature has shown in multiple studies to impact the people that view it and use it in positively manner. The green roofs at Memorial Stadium have the same potential to positively affect the emotions of the students and faculty at Kansas State.

Restorative Properties

GI, like green roofs, also provides for a chance to allow restorative properties that can be taken advantage of by students and faculty at Kansas State. Restorative properties of GI include attention restoration, physical restoration, and stress restoration. Restoration refers to the ability to help people recover from fatigue, regain focus, reduce stress, and aid in physical recovery, when they are exposed to natural elements. Since students have such a mental strain through, school work, projects, tests, and multiple other things that are mentally taxing it is important for students to have a healthy way to be able to refocus and revitalize.

A study done in Michigan, where participants were asked to rate and discuss how they felt about the views from their windows, found that people felt less distracted and were more satisfied when they had a view of nature (Kaplan,Rachel 2001). The restorative properties from just being able to view GI is important because it is seen more than it is used, providing more people with an opportunity to take in the benefits. Felsten,Gary (2009) found that students in college perceived scenes of nature or simulated nature more restorative than scenes that do not have natural elements. Felsten found natural elements are perceived as an important to people, and that natural elements make people more productive.

A study that focused on cognitive benefits of interactions with nature, was conducted by Berman,Marc G.(2008) The study had students fill out an assessment that recorded their moods as well as test their attention performance. The students did this twice on a walk through a natural setting, and then a week later through an urban setting. The results found higher scores on the attention performance tests after the walk in the park than after a walk in a natural environment, thereby demonstrating nature's ability to restore attention.

Although this section looks in depth at psychological benefits to health and wellbeing, it is important to look at physical restoration that has been linked to viewing nature. A famous study that was performed by Ulrich looked at correlations between recovery time and patients and the views the patients had in their hospital rooms. The study consisted of 46 patients that were recovering from a common gall bladder surgery. The patients were grouped in pairs of twos then one was put into a room with a view of trees, and the other into a room with a view of a brick wall. They found that in the patients who had the view of trees had a short in hospital recovery time, asked for fewer pain medication, and had fewer negative evaluations from nurses, and had lower amount of post-surgical complications than the group with the view of the brick wall. (Ulrich,Roger S. 1984)

The restorative properties of nature can be quite beneficial to many people. GI, like the green roofs at Memorial Stadium can play an important role in the success of the students, by providing them means to recuperate from their mentally taxing days, recover from stressful situations, and potentially reduce physically recovery time.

Cleary GI has many positive psychological benefits that can be utilized by students and faculty. Stress reduction, increased positive affect, and restoration all can help students cope with their transition into college, their busy lives, and give them the tools to help them relax and gear up for the next day. But, psychological benefits are increased when there is increased physical health as well. In the next section, we will discuss the physical benefits of GI, and how it can help reinforce psychological benefits.

Physical Benefits

The second type of benefits one can receive from GI is physical benefits. These benefits are primarily benefits that a person will receive to the improvement of their physical being. Being outdoors and active, can positively affect a person's physical health. Increased physical activity allows people to lose weight and fight other health related problems caused by obesity, reduces chances of cardiovascular disease, and improves mental health. There is no argument in the fact that increase physical activity has positive health benefits, but just to what extent does GI play in increased physical activity? The next section attempts to find out how effective, GI and greenspace are at increasing physical activity that leads to physical health benefits. Most of the studies discussed deal with green space and proximity to the user. These studies aim to find out if there is a connection physically healthier people and greenspaces.

To find out if GI increases physical health researchers perform proximity studies in an attempt to find a correlation between nearby green space and increase physical health. A 2005 study in Bristol England looked at a relationship between access to greenspace, physical activity, and obesity. The study consisted of a survey that had 20,140 individuals. They found that people who live closer to greenspace use them more than people that live farther away, they also found people who do use greenspace are not as likely to be overweight (Coombes,Emma 2010). Giles-Corti, Billie (2005) which looked at public open space (green space) proximity and an increase in walking found that access to large green spaces with attractive features lead to higher levels of walking, but they find that ordinary green spaces with less attractive feature are not associated with increased levels of walking. These studies show that people who live closer to green space, usually large open space tend to be more physically healthy than those that don't.

On the other hand, some research has shown that there is not a connection to green space and increased physical health/increased physical activity. Hillsdon,M. (2006) carried out a study in Norwich, UK where he used GIS technology in associations with surveys from 4950 respondents to find if there were relationships between the hours of physical activity and access to greenspace. The surveys asked questions about their health and level of activity and then use in conjunction with the GIS information. The results showed that there were no associations between number of hours of physical activity and access to greenspace, nor was there an association to higher activity levels with larger, more attractive greenspace.

A study conducted in the Netherlands that look to see if there was a connection to access to greenspace and physical activity. To do this they used national survey in which 4899 people responded then used the respondent's geographic information. A 1 kilometer and 3-kilometer diameter circle around each respondent was drawn and green spaces in the circles were counted. The result of the study showed that there was no association between the access to greenspace and physical activity (Maas,Jolanda 2008).

Another study that shows nor correlation to greenspace and increased health was carried out in Ontario, Canada that looked at the health of children in proximity to parks. The study used parents to give information based on the height weight of their children, that information was then cross reference with GIS maps of the local area and found again that there was no association of proximity and physical activity levels (Potwarka,Luke 2008).

Physical activity which is great for physical health, is still widely up for speculation with many studies that show different results. However, despite these inconsistent results, it is commonly accepted that although access to GI allows the opportunity for physical activity, it doesn't necessarily follow that people are going to use the green space, but, people that use green spaces are less likely to be overweight, and have increased physical health.

Increasing physical activities and lowering chances for obesity and heart disease are only one function aspect that GI influences are physical being. Also, worth noting is the ability of GI to provide a myriad of ecosystem services that also contribute to our health through improving the quality of the environment around us. The obvious of these services are water filtration and improved air quality, but there are many more. GI can improve our surrounding environment while at the same time providing a venue for physical activity, both of which can be of great benefit to students and faculty through the green roofs at Memorial Stadium.

Social Benefits

Aside from physical and mental benefits, GI also plays a role in social behavior and can increase social capital. GI can increase social activity, attract mixed groups of people, and aid in the development of social ties. The ability of GI to provide social benefits is very beneficial, especially to college students. With GI, like the green roofs over Memorial Stadium, college students potentially can form ties to people with different backgrounds, and benefit from increased social interactions.

GI can help can help people increase social activity by providing a “hub” for people to meet. A study conducted in Chicago that looked at low income areas and whether green spaces allow for more social activity. It was found that buildings adjacent to green spaces “greener common spaces had more social activities and more visitors, knew more of their neighbors, reported their neighbors were more concerned with helping and supporting one another, and had stronger feelings of belonging”(Kuo,Frances 1998). Greenspace allows for a place for people to meet and get to know one another, from there people develop social ties and start to form a sense of community.

Nature is universal beneficial and through the concept of biophilia which is defined as “the innate tendency to focus on life and lifelike processes” (Rose,Anthony L. 2011). Biophilia is an instinctive bond between humans and other living organisms, this allows for people for people with all backgrounds and different demographic segments to place to interact. A study in Chicago, was carried out by conducting interviews with older residents then assessing their nearby green spaces and their social relationships. The results showed that the there was a positive relationship between the availability of green space and social integration of elderly residents. This shows that green spaces provide an opportunity to have mixed groups where people from all walks of life can interact and build social capital (Kweon,Byoung-Suk 1998).

Additionally, GI can help create social ties, a study that looked at the relationship between the amount of vegetation and crime in urban areas. The study looked at 98 inner city apartment buildings determined how green the surroundings of the buildings were and then looked at crime statistics around this building. The results show that the greener the buildings were the lower the crime rates were surrounding it. It found that property crimes and violent crime both went down when the amount of vegetation went up (Kuo,Frances E. 2001). Because people are forming more social ties and more involved in the community they have less of a reason to deviate into crime.

GI’s ability to increase social capital is quite strong. The benefits for increased social interaction especially for college students is understated. College students can greatly benefit from networking, finding and developing social support, and meeting people from many different backgrounds. The university experiences the benefits of a safer campus with reduction of crime as well as a greater sense of community that the green roofs over Memorial Stadium can offer.

Summary

Green infrastructure is a very powerful tool that can be used to positively affect the lives of people in its surroundings. GI allows for many benefits for human health and wellbeing and has multiple psychological benefits such as stress relief, positive affect, and restoration properties, and while not a driver for people to increase in activity levels, its use show positive correlation to physical health. GI also allows for positive social interactions between mixed groups of people, as well as indirectly lower crime, and build a sense of community. GI like the green roofs on Memorial Stadium are great for the entire campus and the surrounding community. Students can make friends, recoup from a stressful day, and/or can refocus for their next class or assignment. The benefits that people can receive from the GI are incredible and should not be overlooked.

The benefits of GI can have a huge impact on the students and faculty here at Kansas State University. Many of these benefits, such as; stress relief, restoration, and increased positive affect, a venue for physical activity, regulating ecosystem services, increasing social activity, providing people with opportunities to interact diverse people, and helping form a sense of community that makes the campus safer, provide a function for the students, staff, and university that would otherwise cost money if there was no GI. The value of the benefits that GI provides is of great importance and must be considered when looking at the water energy balance of the Memorial Stadium green roofs. The actual monetary value of these services may be hard to ascertain but it doesn't mean that they should be excluded from the discussion.

METHODS

Substrate Analysis

The media used at the Memorial Stadium Green Roof is predominantly composed of sand gravel. A small portion of the volume is a commercialized peat mixture that increases the organic matter content to average 2.0%.

Comparing this substrate to the Konza Prairie is near white vs black. The Konza prairie is found to have high clay textures (up to ~60%), which encourages aggregate stability, water infiltration, nutrient/water holding capacity, and structural stability for plants and their roots.

An analysis of tension vs water content of the Memorial Stadium Green Roof and a typical clay soil explains the difficulty that plants must undergo to receive water in the different soil types, as shown in figure 7. There is more tension at greater water contents in a clayey subsoil due to smaller pore size. However, this also explains a sand's inability to hold water for plant use, forcing them to use water during application times. In the case of the Memorial Stadium Green Roof, the native grasses found on the Konza prairie are required to rely on irrigation events rather than rainfall and soil reserves.

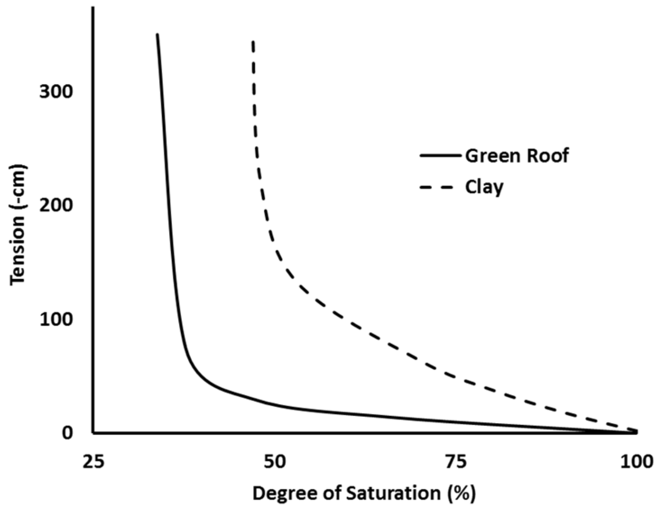


Figure 7. Water release curve comparing the Memorial Stadium Green Roof substrate (sand) to a soil similar to Konza Prairie (clay).

Microbial Composition

The microbial abundance is determined using a method known as Phospholipid Fatty Acid (PLFA) analysis. The raw data collected from a sample of topsoil, to a depth of 10cm, reveals the ratio of biomarkers that are found in the sample. These biomarkers are representative of phospholipids that are specific to the membrane of a specific gram positive or gram negative bacteria, an actinomycete, or AMF, or Fungal species. A series of calculations is used to convert these ratios into concentrations by mass, and then condenses the biomarkers to be group by microbial group, and finally into relative abundance to one another.

Sample collection took place in the second week of October, 2016 at two different sites. Duplicate samples were taken from the West side of Memorial Stadium green roof, and duplicate samples were taken from the Konza Prairie. The sites were sampled within one hour of each other and placed in Ziplock baggies that were stored at four degrees Celsius. Samples were then placed in small plastic containers, covered with mesh, and placed in a freeze dryer at negative fifty degrees Celsius for 72 hours. Samples were then further processed with a mortar and pestle, crushed to a fine dust, and frozen again at four degrees Celsius. The next process is a chemical extraction that takes place over 5 or 6 days (Balser, 2015). This section of the experiment was conducted by Tiffany Carter in the Soil Testing lab located in Throckmorton Hall on Kansas State University in a lab overseen by Dr. Charles Rice.

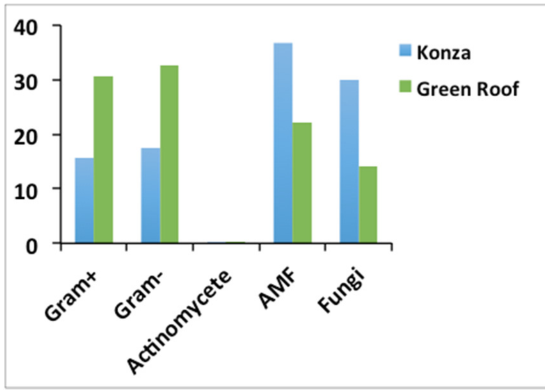


Figure 8. Phospholipid Fatty Acid (PLFA) analysis of samples taken from Konza Prairie and the West side of the green roof at Memorial Stadium at KSU.

Sample	Gram (+)	Gram (-)	Actinomycete	AMF	Fungi
Konza-1	15.2649	17.8644	0.15089	39.6341	27.0855
Konza-2	16.0790	17.1406	0.01878	33.8857	32.8757
Green roof-1	14.3102	13.1046	0.02450	44.1557	28.4048
Green roof-2	47.1298	52.1849	0.06165	0.04213	0.02656

Table 4. Raw data from PLFA. Biomarkers abundance relevance to each other.

Table 4 shows the data as individual samples in % abundance of one microbial form to another. These results show inconsistencies between the green roof samples even though they were both taken at a depth of 10cm and within 2 feet of each other. Green roof-2 shows many more bacteria:fungi, while Green roof-1 shows more fungi:bacteria. These results were averaged and represented as such in figure 8. The Konza samples were shown to be very similar between the duplicates; both showing higher AMF/fungi:bacteria ratios.

Water Use Efficiency

While moisture data for the soil at the Memorial Stadium green roof is collected, little to no data is collected concerning the retention and detention rates of the roofs to determine its impact on the runoff. Therefore, the greatest method for improving water-energy balance given the current knowledge of the roofs performance is to improve irrigation practices.

The green roof is watered every day but Sunday at around 2am and 7am, totaling over 7000 gallons of irrigated water applied each data. While the concern for the health of the plant life at the roof in its infancy is important, it is important to regulate irrigation rates based on the actual need of the roof.

To determine the roof's need for irrigation, the evapotranspiration potential of the vegetation on the roof was estimated based on climate data taken from the top of a nearby building and from the Konza Prairie. ASCE has determined a Standard Reference Evapotranspiration Equation developed to standardize the method for finding or transferring crop coefficient. Factors such as vapor pressure, net radiation and adjusted wind speeds are used to analyze the ET. This was an important finding because of how difficult it is to physically measure ET rates. The equation used is:

$$ET_{sz} = \frac{0.408\Delta(R_n - G) + \gamma \frac{C_n}{T+273} u_2 (e_s - e_a)}{\Delta + \gamma(1 + C_d u_2)}$$

Two sets of climate data were used, Seaton Hall and the Konza, because both represent different factors that are prevalent at the green roofs. Seaton Hall is not exactly at the location of the green roof observed, but it too is in a city landscape and therefore has similar albedo effects, cloud cover, pollutants, and so on. The Konza Prairie represents a more natural landscape and the factors relevant to that environment, but also demonstrates the ET capacity that is standard for the type of plant life established on the green roof.

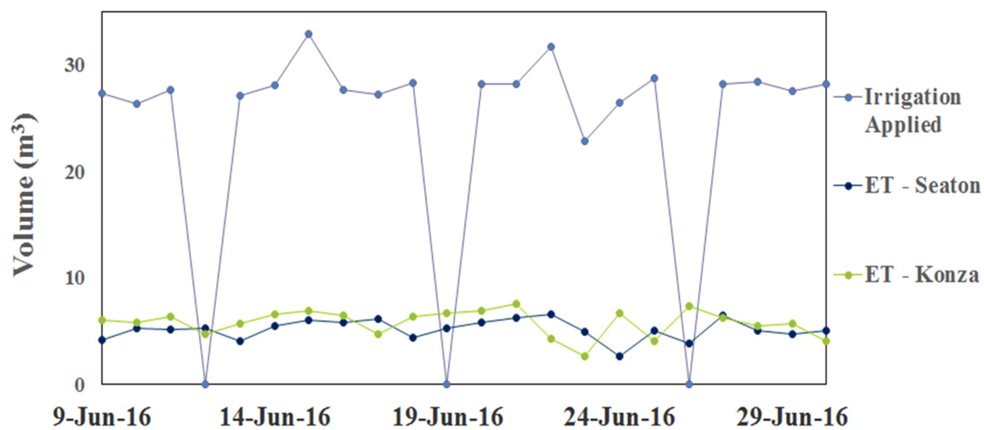


Figure 10. Diagram monitoring results for irrigation applied at the Memorial Stadium compared to calculated ET potential based on two sources of climate data.

After calculating the ET potential, the data was converted and multiplied over the entire green roof. The results found were then compared to the data collected on site for the amount of irrigated water applied to the roof each day.

CONCLUSIONS

An analysis of the ET potential of the Memorial Stadium green roof compared to the amount of irrigated water applied each day demonstrates a gross overuse of water for the sake of establishing the plant life. On average, the roof is being irrigated three or four times more than its capacity to use the water. The ramifications of this practice are steep considering the purposes green roofs are typically installed for such as increased water retention and detention on the roof that reduces and slows runoff. However, given the amount of irrigation, the roof may be causing runoff. Additionally, because the irrigation is not well-monitored, there were many days the roofs watered on the same day as a rainfall event. Thus, reducing the roofs ability to stop or even slow the release of runoff as the soil is already saturated and the vegetation is already inundated with water to take up. However, if the soil and plant life is maintained at less drastic levels, the roofs might be able to play a more significant role in delaying peak discharge times and lengthening the discharge rate.

The Memorial Stadium green infrastructure is currently being over-irrigated and is therefore hindered in it performance in regards to water-energy balance. It is the recommendation of this study that the irrigation rate be greatly reduced to at least an estimated ET potential rate. Additionally, further investigations into more conservation-based irrigation practices, such as collecting and using greywater, should be done to further eliminate unnecessary overuse.

The microbial data is consistent with ideas presented earlier; a more stable aggregate and less disturbed soil, as found at Konza, will show more fungi when compared to more disturbed or less nutrient stable media, as found at Memorial. The inconsistencies between green roof samples may be due to error in the PLFA, or potentially to inconsistencies with the media and plant life dispersal within the green roof itself. The green roof is also a new establishment (within 2 years old), in comparison to soils at Konza prairie that are undisturbed and contain higher clay content than found at Memorial Stadium. Further research is needed to understand the significance in difference between gram positive and gram negative bacteria and their roles in soil microbiology.

FUTURE RESEARCH

Media Selection

There are many paths that are yet to be discovered in green roof engineering. With the interest in Memorial Stadium being a mimic system to that of a native prairie, it would be valuable to have data of a deeper green roof system that also has a sandier media. Not only would this bring research to green roof data, it would also allow plant physiologists to analyze growth and productivity of native grasses in a non-native setting. Data that would be researched would be root length, nutrient uptake, water uptake, and survival of the system.

Microbes

There is a great need for further research on the interactions between soil microorganisms (fungi:bacteria ratios) and the plant communities, soil aggregates, and nutrient cycling process that they encompass. It is necessary to identify microbes by genus and species within a spoil sample. The interactions and processes of specific bacteria are now being identified and quantified through DNA/RNA sequencing and enzyme activity profile development in the soil. (Gupta et al. 2015). These results may help understand the interactions and competition between fungi and bacteria at different soil media depths and the enzymes associated with each (Lange Markus et al. 2014). As well as their specific parts in nutrient cycling and performance of a soil. Assessment of soil microbes throughout different climates and seasons must also be analyzed as well as how plant species richness and density affect soil microbes.
With the interest and development of green roofs increasing, more research must be done on improving soil media to reflect natural soils with bacteria and fungi compost tea inoculations. The microbes will enable green roofs to sustain regional climate stresses and variability with less need for additive care like irrigation and fertilizers, creating a more sustainable system (Molineux et al. 2014). On the same note, more research is being conducted on harvesting energy from microorganism through systems like the Microbial Solar Cell and the Plant-Microbial fuel cells

discussed earlier (Strik et al. 2011). Implementation of energy harvesting mechanisms could potentially enable irrigated green roofs to be a self-sustaining system and excess energy production.

Water-Energy Balance

There is a ton of potential for further investigation into the water-energy balance of the Memorial Stadium green roof. By monitoring the air-conditioning usage and cost between the stadium and a nearby building of similar size or even with information about the stadium before the roofs were constructed, the thermal insulation capacity of the roof could be ascertained. With more data collected on the retention and detention capacity of the roofs, how the roofs impact the storm water runoff during rainfall events could be better understood and utilized. This is a significant finding to learn and capitalize on especially for the City of Manhattan since there are so many problems with excessive runoff overflowing the storm water system.

Aesthetic Performance

The field of studying the influence that GI has on the human health and wellbeing is becoming increasingly popular. There are have been many studies that show it has a multitude of positive impacts on people. However, there is a general call for more solid science and a general shift towards firmer evidence. The majority of the research studies that I review heavily relied on self-assessment surveys. These types of surveys are inherently susceptible to flaws including wording of the questions, interpretation of the questions, dishonesty, and/or respondents failing to answer all the questions. Also, as some studies indicated, there are multiple reasons for different responses to occur in different places and people and groups of people. One of the biggest struggles of this field of study is to limit the number of variables that are being observed so that the variable being tested is the sole variable leading to a different result and then later a conclusion. Until we find a way to limit the variables undoubtedly it is nearly impossible to draw solid results that can be applied to every situation. So future research needs to orient in such a way to use more solid science, such as the use of concentrated cortisol found in hair to determine the level of stress, in hopes to advance this field and be able to take steps in finding more truths of how GI or nature in general influences health and wellbeing.

REFERENCES

Allison, V. J., Miller, R. M., Jastrow, J. D., Matamala, R., & Zak, D. R. (2005). Changes in soil microbial community structure in a tallgrass prairie chronosequence. Soil Science Society of America Journal, 69(5), 1412.

Anderson, T. M., Dong, Y., & McNaughton, S. J. (2006). Nutrient acquisition and physiological responses of dominant serengeti grasses to variation in soil texture and grazing. *Journal of Ecology, 94*(6), 1164-1175.

Aspinall, P., Mavros, P., Coyne, R., & Roe, J. (2015). The urban brain: Analysing outdoor physical activity with mobile EEG. *British Journal of Sports Medicine, 49*(4), 272.

Austin, G. (2014). *Green infrastructure for landscape planning integrating human and natural systems*. Hoboken: Hoboken: Taylor and Francis.

Baller, Teri C. phospholipid fatty-acid analysis (PLFA). (2015). Berkeley. Nature.com. <http://nature.berkeley.edu/soilmicro/methods/BalserPLFA.pdf>

Bell, S. L., Phoenix, C., Lovell, R., & Wheeler, B. W. (2014). Green space, health and wellbeing: Making space for individual agency. *Health and Place, 30*, 287.

Berman, M. G., Jonides, J., & Kaplan, S. (2008). The cognitive benefits of interacting with nature. *Psychological Science, 19*(12), 1207.

Berndtsson, J. C. (2010). Green roof performance towards management of runoff water quantity and quality: A review. *Ecological Engineering, 36*, 351+.

Berndtsson, J. C., Emilsson, T., & Bengtsson, L. (2006). The influence of extensive vegetated roofs on runoff water quality. *Science of the Total Environment, 355*(1–3), 48-63.

Berretta, C., Poë, S., & Stovin, V. (2014). Moisture content behaviour in extensive green roofs during dry periods: The influence of vegetation and substrate characteristics. *Journal of Hydrology, 511*, 374-386.

Bland, H. W., Melton, B. F., Welle, P., & Bigham, L. (2012). Stress tolerance: New challenges for millennial college students. *College Student Journal, 46*(2), 362-375.

Bonoli, A., Conte, A., Maglionico, M., & Stojkov, I. (2013). Green roofs for sustainable water management in urban areas. *Environmental Engineering and Management Journal, 12*(S11), 153-156.

Brady, N. C., & Weil, R. R. (1999). *The Nature and Properties of Soils* (12th ed.). New Jersey: Prentice-Hall, Inc.

Bratman, G. N., Hamilton, J. P., & Daily, G. C. (2012). The impacts of nature experience on human cognitive function and mental health. *Annals of the New York Academy of Sciences, 12491*(1), 118-136.

Bristow, K. L., Campbell, G. S., & Calissendorff, C. (1984). The effects of texture on the resistance to water movement within the rhizosphere. *Soil Science Society of America Journal, 48*, 266-270.

Brockett, B. F. T., Prescott, C. E., & Grayston, S. J. (2012). Soil moisture is the major factor influencing microbial community structure and enzyme activities across seven biogeoclimatic zones in western Canada. Soil Biology and Biochemistry, 44(1), 9-20.

Burns, R. G. (2014). Soil biology & biochemistry citation classic XII. Soil Biology and Biochemistry, 68, A3.

Campbell, L. K., Wiesen, A., United States Forest Service Northern, Research Station, & Meristem (Organization). (2009). *Restorative commons creating health and well-being through urban landscapes*. Newtown Square, PA: New York, NY: Newtown Square, PA: USDA Forest Service, Northern Research Station; New York, NY: Meristem.

Coleman, D. C., Reid, C. P. P., & Cole, C. V. (1983). Biological strategies of nutrient cycling in soil systems. Advances in Ecological Research, 13, 1-55.

Coombes, E., Jones, A. P., & Hillsdon, M. (2010). The relationship of physical activity and overweight to objectively measured green space accessibility and use. *Social Science & Medicine, 70*(6), 816-822.

Coutts, C., & Hahn, M. (2015). Green infrastructure, ecosystem services, and human health. *International Journal of Environmental Research and Public Health, 12*(8), 9768-9798.

DeRoma, V. M., Leach, J. B., & Leverett, J. P. (2009). The relationship between depression and college academic performance. *College Student Journal, 43*(2), 325-334.

Falsone, G., Celi, L., Stanchi, S., & Bonifacio, E. (2016). Relative importance of mineralogy and organic matter characteristics on macroaggregate and colloid dynamics in MG-Silicate dominated soils. Land Degradation & Development, 27(7), 1700-1708.

Felsten, G. (2009). Where to take a study break on the college campus: An attention restoration theory perspective. *Journal of Environmental Psychology, 29*(1), 160-167.

Fernandez, A. L., Sheaffer, C. C., Wyse, D. L., Staley, C., Gould, T. J., & Sadowsky, M. J. (2016). Associations between soil bacterial community structure and nutrient cycling functions in long-term organic farm soils following cover crop and organic fertilizer amendment. Science of the Total Environment, 566–567, 949-959.

Francis, J., Wood, L. J., Knuiman, M., & Giles-Corti, B. (2012). Quality or quantity? exploring the relationship between public open space attributes and mental health in Perth, western Australia. *Social Science & Medicine, 74*(10), 1570-1577.

Gidlow, C. J., Randall, J., Gillman, J., Smith, G. R., & Jones, M. V. (2016). Natural environments and chronic stress measured by hair cortisol. *Landscape and Urban Planning, 148*, 61-67.

Gidlow, C. J., Randall, J., Gillman, J., Smith, G. R., & Jones, M. V. (2016). Natural environments and chronic stress measured by hair cortisol. *Landscape and Urban Planning, 148*, 61-67.

Giles-Corti, B., Broomhall, M. H., Knuiman, M., Collins, C., Douglas, K., Ng, K., Donovan, R. J. (2005). Increasing walking: How important is distance to, attractiveness, and size of public open space? *American Journal of Preventive Medicine, 28*(2), 169-176.

Godbey, G., & Others, A. (1993). Reality and perception: where do we fit in? *Parks and Recreation, 28*(1), 76-83.

Graceson, A., Hare, M., Monaghan, J., & Hall, N. (2013). The water retention capabilities of growing media for green roofs. *Ecological Engineering, 61, Part A*, 328-334.

Graceson, A., Monaghan, J., Hall, N., & Hare, M. (2014). Plant growth responses to different growing media for green roofs. *Ecological Engineering, 69*, 196-200.

Grahn, P., & Stigsdotter, U. A. (2003). Landscape planning and stress. *Urban Forestry & Urban Greening, 2*(1), 1-18. doi:10.1078/1618-8667-00019

Gupta, Vadakattu V S R, & Germida, J. J. (2015). Soil aggregation: Influence on microbial biomass and implications for biological processes. Soil Biology and Biochemistry, 80, A9.

Harper, G. E., Limmer, M. A., Showalter, W. E., & Burken, J. G. (2015). Nine-month evaluation of runoff quality and quantity from an experiential green roof in Missouri, USA. *Ecological Engineering, 78*, 127-133.

Hartig, T., Evans, G. W., Jamner, L. D., Davis, D. S., & Gärling, T. (2003). Tracking restoration in natural and urban field settings. *Journal of Environmental Psychology, 23*(2), 109-123. doi:10.1016/S0272-4944(02)00109-3

Hartig, T., Evans, G. W., Jamner, L. D., Davis, D. S., & Gärling, T. (2003). Tracking restoration in natural and urban field settings. *Journal of Environmental Psychology, 23*(2), 109-123.

Hill, R. M., Yaroslavsky, I., & Pettit, J. W. (2015). Enhancing depression screening to identify college students at risk for persistent depressive symptoms. *Journal of Affective Disorders, 174*, 1-6.

Hillsdon, M., Panter, J., Foster, C., & Jones, A. (2006). The relationship between access and quality of urban green space with population physical activity. *Public Health, 120*(12), 1127-1132.

Jenny, H. (1941). *Factors of Soil Formation: A System of Quantitative Pedology*. New York: Dover Publications, Inc.

Jiang, X., Wright, A. L., Wang, J., & Li, Z. (2011). Long-term tillage effects on the distribution patterns of microbial biomass and activities within soil aggregates. Catena, 87(2), 276-280.

Journal of environmental management. Amsterdam: Elsevier.

Kaplan, R. (2001). The nature of the view from home: Psychological benefits. *Environment and Behavior, 33*(4), 507.

Kristenson, M., Eriksen, H. R., Sluiter, J. K., Starke, D., & Ursin, H. (2004). Psychobiological mechanisms of socioeconomic differences in health. *Social Science & Medicine, 58*(8), 1511-1522.

Kuo, F. E., & Sullivan, W. C. (2001). Environment and crime in the inner city: Does vegetation reduce crime? *Environment and Behavior, 33*(3), 343.

Kuo, F., Sullivan, W., Coley, R., & Brunson, L. (1998). Fertile ground for community: Inner-city neighborhood common spaces. *American Journal of Community Psychology, 26*(6), 823-851.

Kweon, B., Sullivan, W., & Wiley, A. (1998). Green common spaces and the social integration of inner- city older adults. *Environment & Behavior, 30*(6), 832-858.

Lange, M., Habekost, M., Eisenhauer, N., Roscher, C., Bessler, H., Engels, C., . . . Gleixner, G. (2014). Biotic and abiotic properties mediating plant diversity effects on soil microbial communities in an experimental grassland. PloS One, 9(5), e96182.

Lee, A. C. K., & Maheswaran, R. (2011). The health benefits of urban green spaces: A review of the evidence. *Journal of Public Health, 33*(2), 212-222.

Lin, B., Meyers, J., & Barnett, G. (2015). Understanding the potential loss and inequities of green space distribution with urban densification. *Urban Forestry & Urban Greening, 14*(4), 952-958.

Liu, W., Zhang, Z., & Wan, S. (2009). Predominant role of water in regulating soil and microbial respiration and their responses to climate change in a semiarid grassland. Global Change Biology, 15(1), 184-195.

Maas, J., Verheij, R. A., Spreeuwenberg, P., & Groenewegen, P. P. (2008). Physical activity as a possible mechanism behind the relationship between green space and health: A multilevel analysis. *BMC Public Health, 8*.

Meier, M. (2007). In Mathison M. (Ed.), *A sense of community through an urban greenspace: Perspectives on people and place* ProQuest Dissertations Publishing.

Melissa A. Cregger, Christopher W. Schadt, Nate G. McDowell, William T. Pockman, & Aimée T. Classen. (2012). Response of the soil microbial community to changes in precipitation in a semiarid ecosystem. Applied and Environmental Microbiology, 78(24), 8587-8594.

Molineux, C. J., Connop, S. P., & Gange, A. C. (2014). Manipulating soil microbial communities in extensive green roof substrates. Science of the Total Environment, 493, 632-638.

Nippert, J. B., Wieme, R. A., Ocheltree, T. W., & Craine, J. M. (2012). Root characteristics of C4 grasses limit reliance on deep soil water in tallgrass prairie. *Plant and Soil, 355*(1), 385-394.

Palla, A., Gnecco, I., & Lanza, L. G. (2010). Hydrologic restoration in the urban environment using green roofs. *Water, 2*(2), 140-154.

Pedersen, D. E. (2012). Stress carry-over and college student health outcomes. *College Student Journal, 46*(3), 620-627.

Potwarka, L., Kaczynski, A., & Flack, A. (2008). Places to play: Association of park space and facilities with healthy weight status among children. *Journal of Community Health; the Publication for Health Promotion and Disease Prevention, 33*(5), 344-350.

Razzaghmanesh, M., Beecham, S., & Kazemi, F. (2014). The growth and survival of plants in urban green roofs in a dry climate. *Science of the Total Environment, 476-477*, 288-297.

Rose, A. L. (2011). Bonding, biophilia, biosynergy, and the future of primates in the wild. *American Journal of Primatology, 73*(3), 245.

Roy, R. N., Finck, A., Blair, G. J., & Tandon, H. L. S. (2006). *Plant nutrition for food security.* (No. 16). Rome, Italy: FAO Viale delle Terme di Caracalla.

Shields, B. (2011). In Abbott C., Bassett E., Gibson K., Lang W. and Messer W.(Eds.), *Exploring sense of place of community gardens in Portland.* ProQuest Dissertations Publishing.

Steenwerth, K. L., Jackson, L. E., Calderón, F. J., Stromberg, M. R., & Scow, K. M. (2002). Soil microbial community composition and land use history in cultivated and grassland ecosystems of coastal California. Soil Biology and Biochemistry, 34(11), 1599-1611.

Stovin, V., Poe, S., De-Ville, S., & Berretta, C. (2015). The influence of substrate and vegetation configuration on green roof hydrological performance. *Ecological Engineering, 85*, 159+.

Strik, D. P. B. T. B., Timmers, R. A., Helder, M., Steinbusch, K. J. J., Hamelers, H. V. M., & Buisman, C. J. N. (2011). Microbial solar cells: Applying photosynthetic and electrochemically active organisms. Trends in Biotechnology, 29(1), 41-49.

Ulrich, R. S. (1984). View through a window may influence recovery from surgery. *Science, 224*(4647), 420-421.

United States Department of Agriculture. (1957). *The yearbook of agriculture 1957.* ().United States Government Printing Office.

Van Mechelen, C., Dutoit, T., & Hermy, M. (2015). Adapting green roof irrigation practices for a sustainable future: A review. *Sustainable Cities and Society, 19*, 74-90.

van, D. B., Maas, J., Verheij, R. A., & Groenewegen, P. P. (2010). Green space as a buffer between stressful life events and health. *Social Science & Medicine, 70*(8), 1203-1210.

VanWoert, N. D., D Bradley Rowe, Andresen, J. A., Rugh, C. L., & et al. (2005). Green roof stormwater retention: Effects of roof surface, slope, and media depth. *Journal of Environmental Quality, 34*(3), 1036-44.

Vijayaraghavan, K., & Raja, F. D. (2014). Design and development of green roof substrate to improve runoff water quality: Plant growth experiments and adsorption. *Water Research, 63*, 94-101.

Walker, R. (2016). Density of materials. Retrieved from http://www.simetric.co.uk/si_materials.htm

Wu, C., Mcneely, E., Cedeño-Laurent, J., Pan, W., Adamkiewicz, G., Dominici, F., . . . Spengler, J. (2014). Linking student performance in Massachusetts elementary schools with the "greenness" of school surroundings using remote sensing. *PLoS One, 9*(10), e108548.

Young, T., Cameron, D. D., Sorrill, J., Edwards, T., & Phoenix, G. K. (2014). Importance of different components of green roof substrate on plant growth and physiological performance. *Urban Forestry & Urban Greening, 13*(3), 507-516.

Zartman, R. E. (2006). Soil texture and water management. *American Nurseryman, 203*(5), 32-34. Retrieved from http://search.ebscohost.com/login.aspx?direct=true&db=bai&AN=506658237&site=ehost-live