Impacts of Spatial Heterogeneity of Soil Conditions on Green Roof Plant Growth

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Abstract

Green roofs have been utilized as efficient tools to mitigate climate change for their multiple benefits including reduction of **stormwater runoff**, **heat-island effect**, and **energy consumption.** Spatial variability in soil conditions (e.g., temperature, moisture) appears due to green roofs' varying architectural configurations, which lead to spatial heterogeneity of plant growth.

Research was conducted through **plant growth assessments** by field observations as well as **soil condition measurements** by sensors installed on the green roof of the Richard Weeks Hall of Engineering at Rutgers University.

Soil temperature was determined as the primary factor for plant growth on green roofs. **Spatial heterogeneities** were identified in soil conditions and plant growth. Relationships were developed for the prediction of spatial distribution of plant growth to address the impacts of spatial variability in soil conditions.

Introduction

Urbanization has intensified the global warming process via heat-island effect[1] and excessive energy consumption[2]. Intense rainfall and associate flooding have increasingly occurred as climate change worsens[3]. Green roofs, as engineered ecosystems, are frequently built to address these issues[4-5] by **stormwater quantity reduction**[4], **quality improvement**, **thermal insulation**, and **energy saving**[6-7].

In 2019, Bill A-710 requiring large state buildings in New Jersey to be constructed with green or blue roofs was approved by the NJ Assembly Appropriations Committee[8]. Recently, the New Jersey Department of Environmental Protection (NJDEP) has adopted a revised set of stormwater regulations under N.J.A.C. 7:8[9], which took effect on March 2, 2021, to **mandate the use of decentralized green infrastructure practices** to meet the requirements for water quality control and groundwater recharge. Green roofs are gaining momentum in NJ and beyond due to ecosystem benefits and regulatory requirements.

With increasing applications of green roofs, it is inevitable that many of them will be blocked or shaded by nearby buildings, resulting in spatial heterogeneities of microclimates and thus soil conditions. Identifying heterogeneity of soil conditions and plant growth and evaluating their relationship will provide insights into the **ecosystem benefits** and **spatially optimized plant selection** of green roofs.

Figure 1. Green roof in a highly urbanized city

Figure 2. Spatial variability in microclimates of a green roof due to shade and reflection

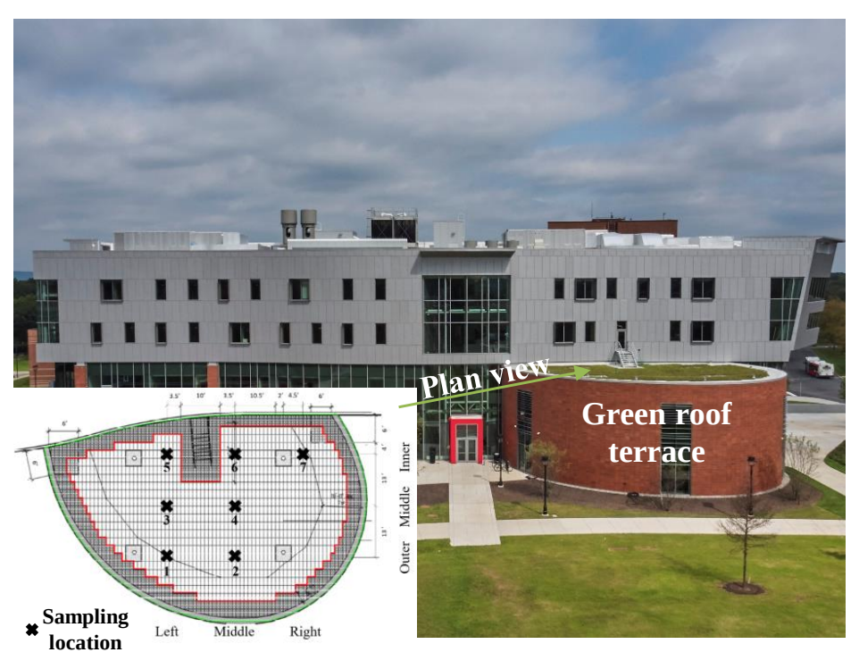

Figure 3. Green roof of the Richard Weeks Hall of Engineering at Rutgers

Methods

Plant assessment: Growth of target plants were assessed monthly from September 1, 2021 to August 31, 2022 using a scoring system with indicators of **vegetation coverage**, **stem length**, **health score**, and **reproductive success**.

Soil measurement: Soil conditions (**temperature** and **moisture**) at sampling points were monitored at an interval of 15 minutes from September 1, 2021 to August 31, 2022 using soil sensors (TEROS 12 Soil Sensor, METER Group, Inc., WA, US).

Statistical analysis: For various soil conditions and plant growth assessment scores among sampling locations, **F-tests** were conducted between every two samples of interest to determine if they had equal variance and **Student's T-tests** (equal variance) or **Welch's t-tests** (unequal variance) were employed to identify significant differences between the two samples.

Results

Annual averages of soil moisture, soil temperature, and plant growth are presented as 3-D column charts in Figure 4 to Figure 6. Apparent **spatial variations** in these parameters can be observed among inner sensors (closest to the building wall), middle sensors, and outer sensors (farthest from the building wall).

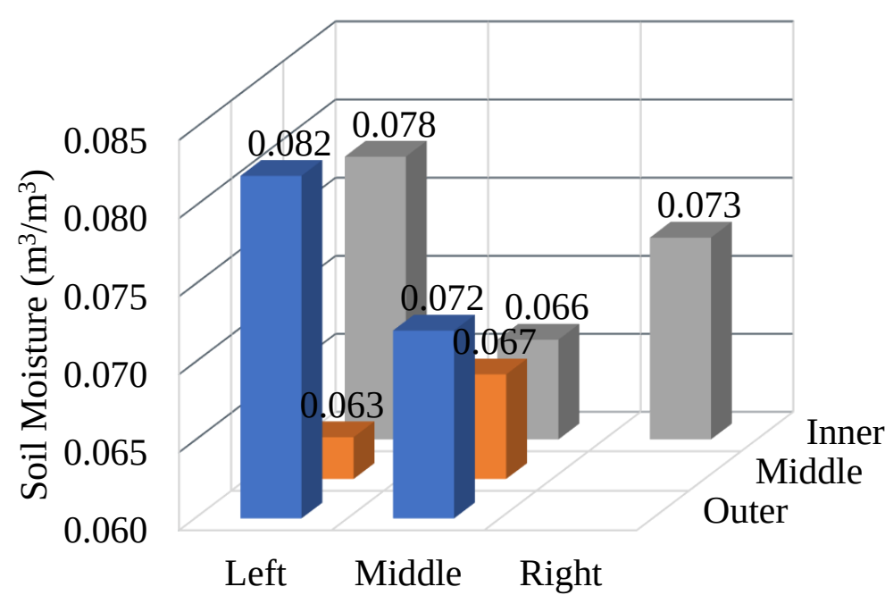

Figure 4. Spatial distribution of annual average soil moisture

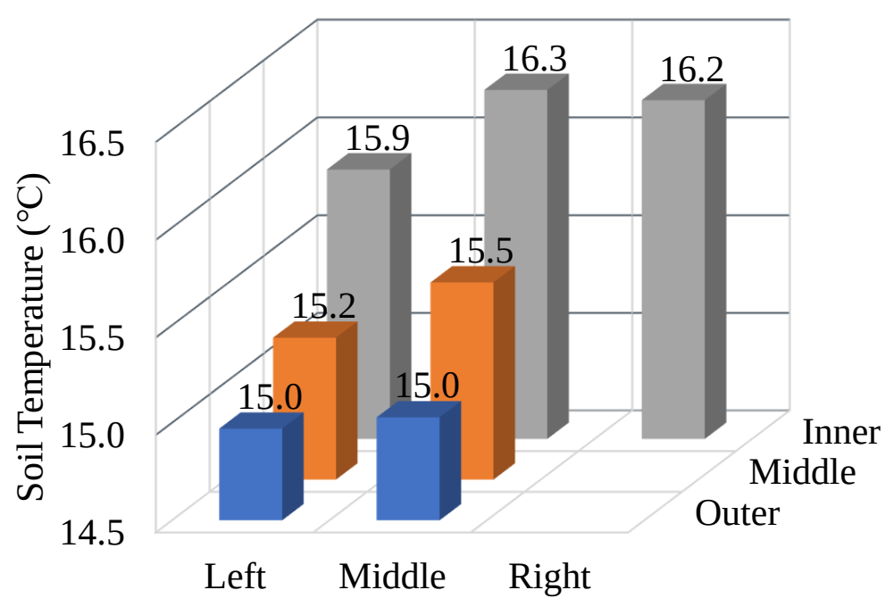

Figure 5. Spatial distribution of annual average soil temperature

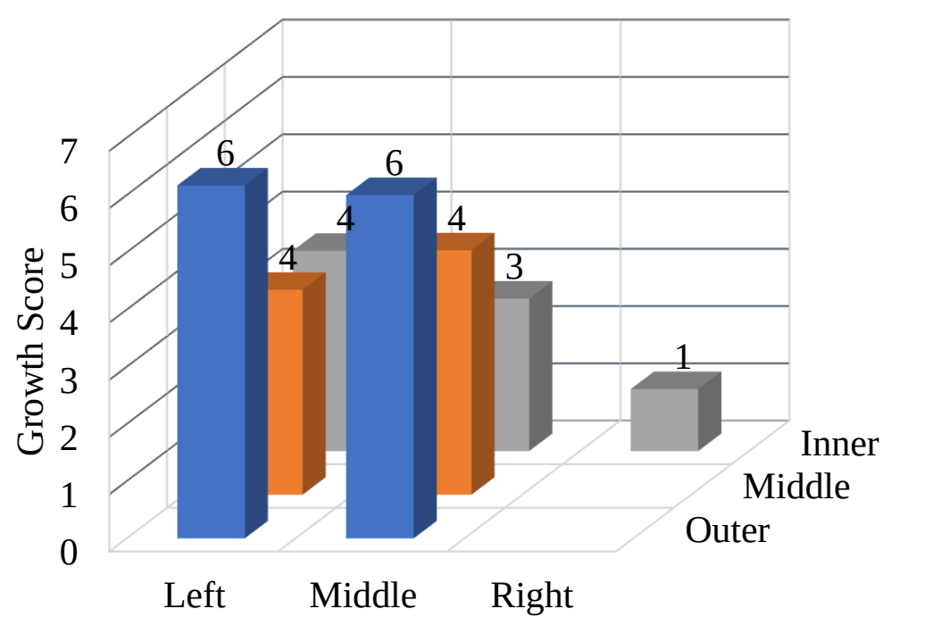

Figure 6. Spatial distribution of annual average growth score

F-tests and t-tests were conducted for sampling locations along the inner-middle-outer direction and results identified **significant (confidence of 95%) spatial differences** in soil moisture, soil temperature, and growth score.

To better understand the impacts of spatial heterogeneities of soil conditions on plant growth, linear regression analyses were conducted among them to establish the relationships, and p-values of intercept and slope were calculated to determine the significance of the predictors (soil moisture and soil temperature). Results showed that **soil temperature** is the **primary** factor for plant growth, while **soil moisture** is **insignificant** in the spatial distribution of plant growth.

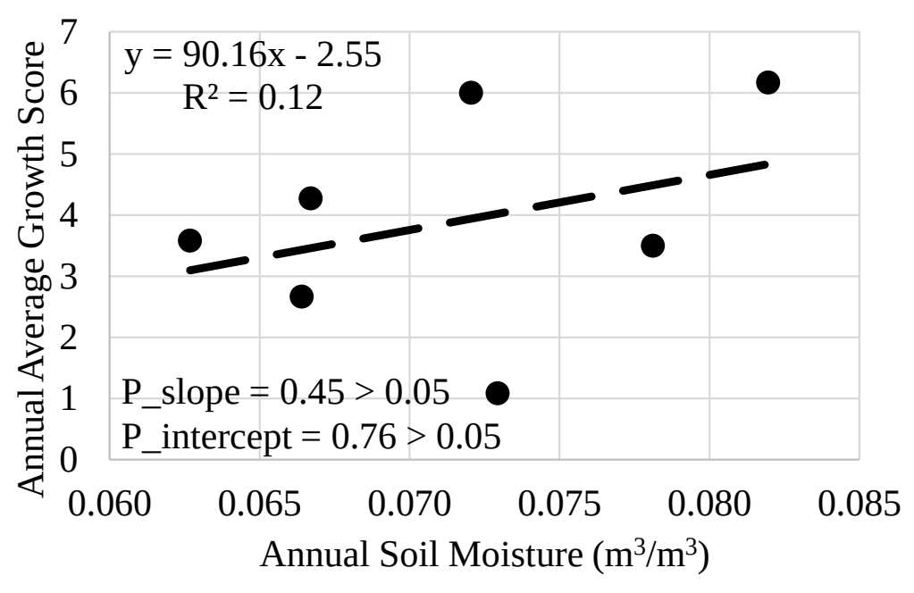

Figure 7. Linear regression: plant growth vs soil moisture

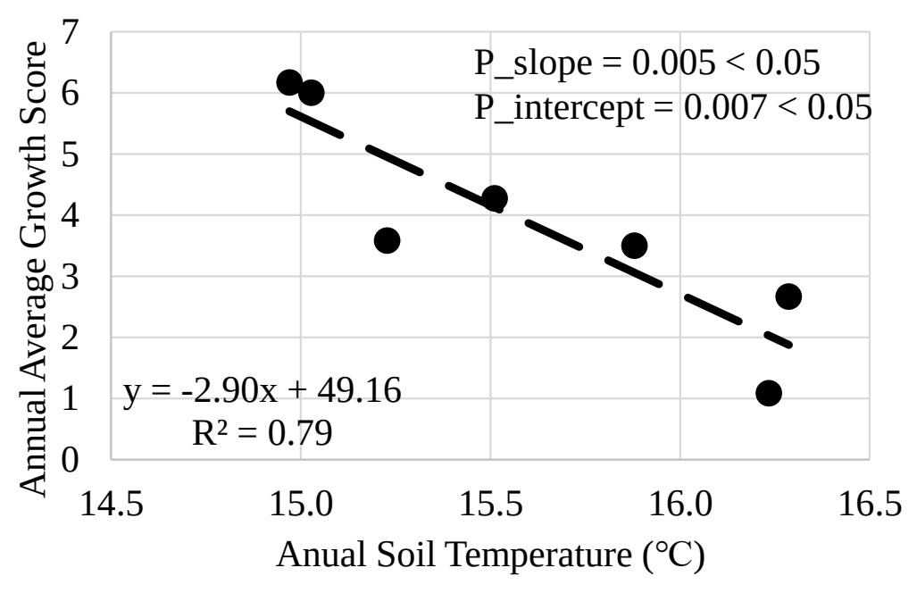

Figure 8. Linear regression: plant growth vs soil temperature

Discussion

Field observations revealed that the green roof was seldom shaded by other parts of the building as shown in Figure 9. Therefore, **shading may not be the decisive factor** in the spatially variability in plant growth regarding this site. Instead, **sun reflections** from the building wall and **winds** might be the reason. The linear regression (Figure 10) between plant growth and the distance to the building wall implies that microclimates (e.g., solar radiation, wind) vary at different locations, resulting in the spatial heterogeneity of soil temperature. This variation further leads to the spatial difference in plant growth.

Figure 9. Annual sun paths[10] above the study roof

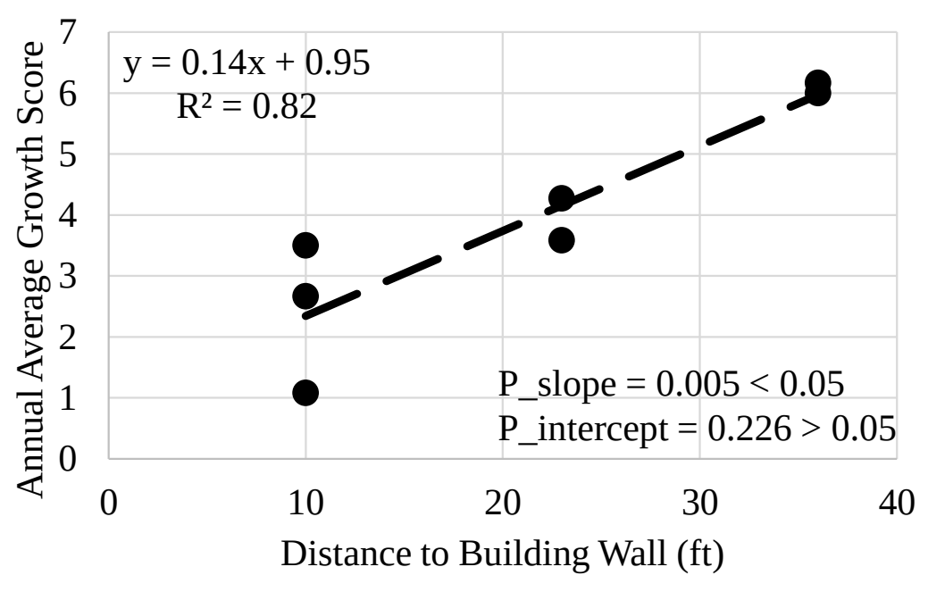

Figure 10. Linear regression: plant growth and distance to building wall

Conclusions

1. Spatial heterogeneities were identified in soil conditions and plant growth.
2. Relationships were established between soil conditions and plant growth.
3. Soil temperature is the primary factor for plant growth on green roofs.
4. Soil moisture is insignificant for the variability in plant growth on green roofs.

Acknowledgment

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