Drew University

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The Effects of Urban Agriculture on Soil Quality

A Thesis in Environmental Science

by

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This work is dedicated to sustainable farmers everywhere, who are not only supplying nutritious food, but advocating for the health of the planet. I would like to thank everyone at *Grow It Green* for allowing me to use their property, and for supplying me with invaluable farm knowledge and experience. I would also like to thank my extended committee, Dr. Mary-Ann Pearsall and Jacob Soule, as well as Leo Ambrogio and Danielle DelRosso for their support and encouragement throughout this process. I would like to especially thank Dr. Shagufta Gaffar for her unwavering support and infectious enthusiasm towards soil. I couldn't have done it without her.

Abstract

As urban agriculture becomes more popular, it becomes increasingly important to evaluate the effect it is having on soil quality, ultimately influencing crop production, as well as surrounding communities. In conjunction with this, having a good understanding of the definition of "sustainable agriculture" and the practices that fall under its umbrella allow us to create more functional and supportive agricultural systems. The objective of this study is to examine the symbiotic relationship of how sustainable urban farming is affecting soils, as well as how the heterogeneity of soil can influence agricultural design and function. The organic urban farm *Grow It Green* (GIG) located in Morristown, New Jersey was used as a case study, not only because of its sustainable practices and research potential, but also because it showcases how valuable these farms can be for providing community resources and opportunities. In order to measure overall soil quality, the physical, chemical, and microbial parameters were all measured through a variety of both field and lab tests. Because this study is the first of its kind at this location, it will serve as baseline data for which future research can refer and compare to.

Table of Contents

Introduction

Soil and Its Significance

Soil is an extremely complex ecosystem with a variety of crucial functions which include, but are not limited to, the provision of food, fiber, and fuel, the decomposition of organic matter, recycling of essential nutrients, detoxification of organic contaminants, nutrient cycling, carbon sequestration, and regulation of water quality and supply (Creamer et al., 2022). In order to truly understand these functions and how to improve them, it is crucial to understand the basics of soil composition and function first. Particularly through an agricultural lens, a productive soil ecosystem can make or break the success of crop yield, which is closely tied to other issues such as food accessibility and insecurity. Recognizing soil and its significance in global systems will not only benefit the health and accessibility of environmental resources, but there is also an economic incentive to upkeep the production of goods such as foodstuffs.

As shown in Figure 1, soil itself is almost entirely composed of minerals, organic matter,

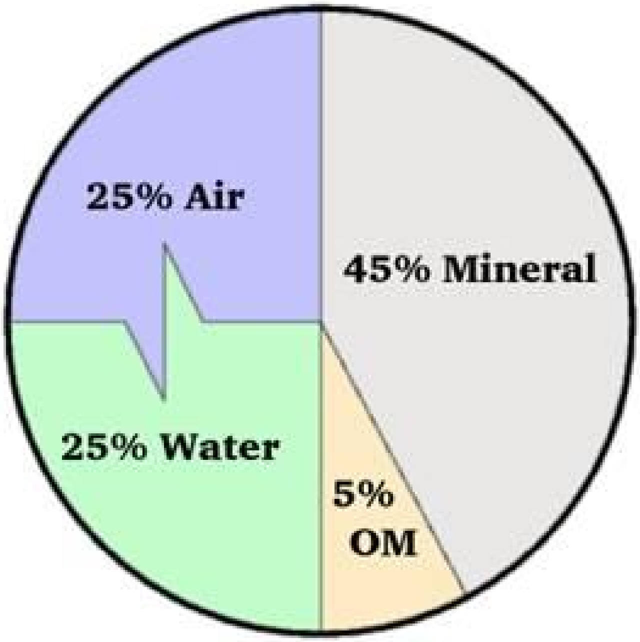

Figure 1. Approximate Composition of Soil (University of Hawai'i, 2024).

air, and water. Although "soil" is by no means an incorrect term, it is more of an umbrella term under which different soil orders fall under. They are based on aspects such as texture, moisture content, and mineral composition. Globally, there are 12 major ones: alfisols, andisols, aridisols, entisols, gelisols, histosols, inceptisols, mollisols, oxisols, spodosols, ultisols, and vertisols

Figure 2. Listing of Global Soil Orders (Earth Review, 2019)

(Figure 2). This classification system provides a universal framework for describing and understanding soil properties, as well the organization of soil knowledge (Dawson et al., 2023). Each order can be found in a variety of locations, however, no single one is ever truly found exclusively in one place. A variety of soil types are found in one specific area, but the area will be geographically depicted by its dominant soil type. As shown in Figure 4, the dominant soil orders in New Jersey are alfisols, entisols, histosols, inceptisols, spodosols, and ultisols. In

Morris County specifically, which is where the testing site is located, ultisols are the most dominant, although there are still traces of ultisols and alfisols. These soil types, specifically alfisols, are known for being particularly fertile and supportive to agriculture due to their inherently fertile parent materials. Climates where alfisols can be found also support growing conditions with their seasonal temperatures, rainfall, and sunlight (Hatfield et al., 2017). Although New Jersey does not contain any of the most productive "breadbasket" soil order known as mollisols, it is one of the top producers of an array of crops such as blueberries, cranberries, peaches, cucumbers, apples, spinach, squash, and tomatoes. New Jersey agriculture also generates over $1 billion in annual revenue (USDA National Statistics, 2022).

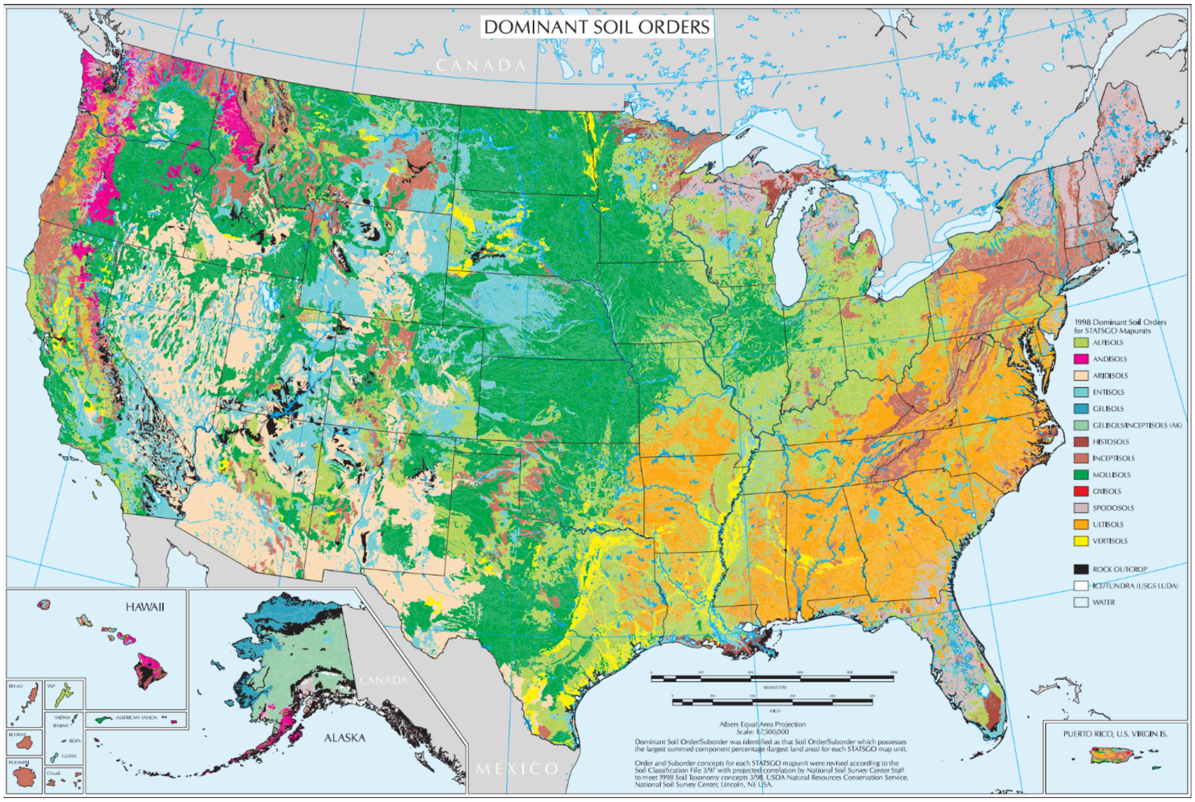

Figure 3. Soil Order Map of the United States (USDA, 2024).

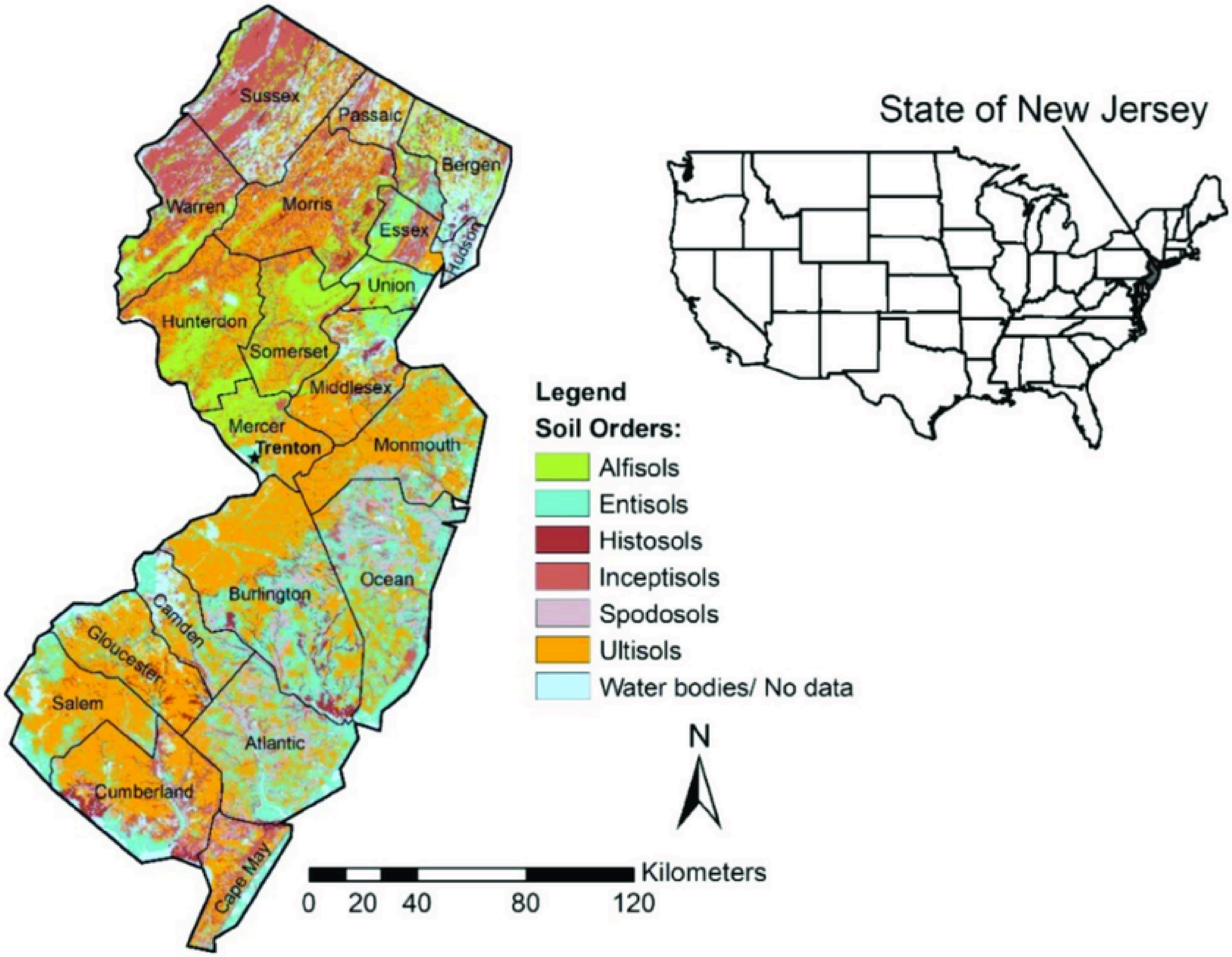

Figure 4. Dominant Soil Orders in the State of New Jersey (Mikhailova et al., 2022).

In addition to global soil order, there is also a standard for determining a soils' texture classification based on its sand, silt, and clay composition. Using the chart showcased in Figure 5, texture can be determined by matching the percentages of each particle type to corresponding

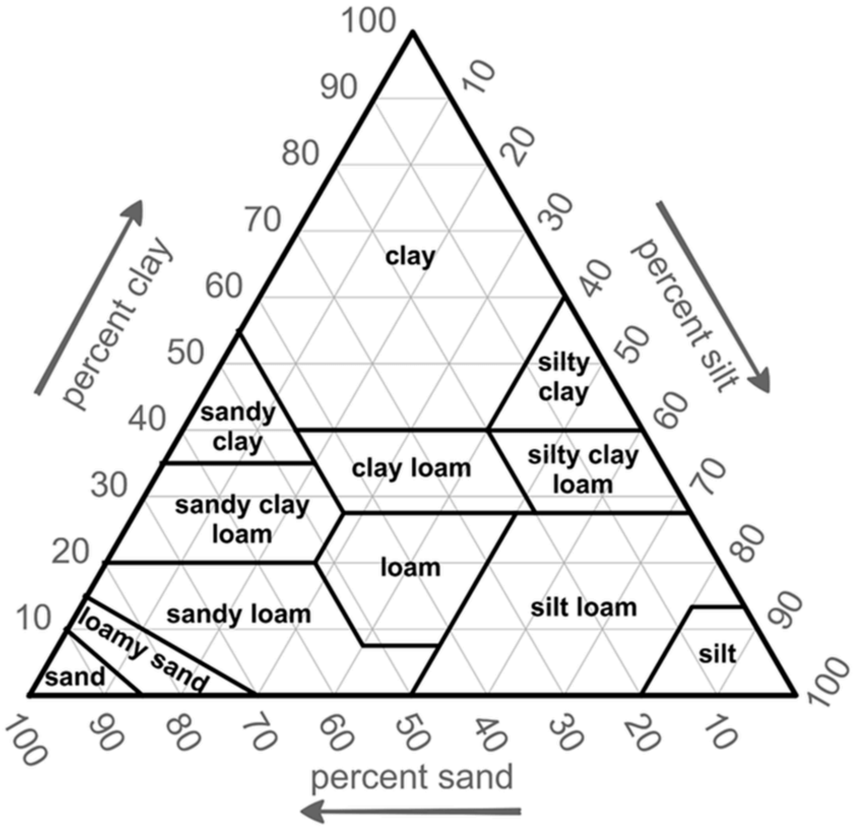

Figure 5. Soil Texture Chart (USDA, 2024).

area. A soil's texture affects soil quality because it determines how a soil can be used, as certain proportions of sand, silt, and clay are more ideal for growing conditions and productivity because of the role particles play in natural processes. For example, sand particles on a molecular level have more space between them in comparison to silt and clay, meaning water can pass through them more easily. Thus, soils with an extremely high sand content are not able to retain as much water as those with larger proportions of silt or clay. Because different crops have such a wide variety of needs, most soil textures are able to support crop growth in some way. However, most crops grow best in soils with a loamy texture, as they have enough pore space for water and air to circulate, but enough small particles to retain important materials such as water and nutrients.

Soil Quality Characteristics

In addition to understanding the basic components of soil, it is also important to understand its functions and formation, which are crucial to its large-scale ecosystem services, such as food production. Soil quality can be defined as “the capacity of a soil to function, within ecosystem boundaries, to sustain crop and animal productivities, maintain or enhance environmental sustainability, and improve human health worldwide” (Yang et al., 2020). Although soil quality is often comparable to soil health, the definition is slightly different. Soil health measures how well a soil is performing its regular functions, and how they might be affected in the future (USDA, 2024). The two terms are able to be used relatively interchangeably, but there are slight differences between them. Overall soil quality is dependent on a wide variety of factors, but is split mainly into three portions: physical properties, chemical processes, and biological characteristics. The specific values for each characteristic that are considered best for agricultural productivity are showcased in Table 2.

Major physical characteristics of soil are color and temperature, but the most important for measuring agricultural soil quality are porosity, bulk density, structure, and water-holding capacity. These properties affect natural processes such as infiltration, nutrient cycling, and erosion (Jat et al., 2018).

Porosity measures a soil's ability to store materials such as air and water, which are essential for plant growth. Bulk density (BD) is the measure of the weight of a soil in relation to its volume. Soil structure affects the accumulation and storage of materials such as carbon, water, and various other nutrients, as well as the ability of plant roots to grow in both width and depth. Water-holding capacity is the amount of water that soil can hold which will then be usable to plants (Herawati et al., 2021). There is a unique window for soil's water-holding capacity, as insufficient water will limit plant growth, and an extreme surplus of water can result in crop harm, as it may result in standing water, soil erosion, and nutrient loss. If a soil does not have the appropriate amount of water in either direction of the scale, it will lead to poor plant growth.

Important chemical properties of soil include pH, and a variety of both micro and macronutrients, specifically nitrogen, phosphorus, and potassium (NPK). Soil pH is a measurement of reaction that is measured on a scale of 0 to 14. The scale is grouped into the following categories: ultra-acidic (<3.5), extremely acidic (3.5-4.4), very strongly acidic (4.5-5.0), strongly acidic (5.1-5.5), moderately acidic (5.6-6.0), slightly acidic (6.1-6.5), neutral (6.6-7.3), slightly alkaline (7.4-7.8), moderately alkaline (7.9-8.4), strongly alkaline (8.5-9.0) and very strongly alkaline (>9.0) (Msimbira et al., 2020). Agricultural productivity is best around pH 6.0-7.5 (Table 2) due to the availability of nutrients and microbial productivity. Soil that is outside of the optimal range will cause a variety of complications for both soil health and crop production. Most agricultural products thrive at a pH near neutrality (Lindström et al., 2010).

pH also correlates directly with the availability of macro and micronutrients, both of which are important for the health of the soil and the ability to support crop growth. As shown in

Table 1, of the essential elements which are needed for plant growth, nitrogen, phosphorus, and potassium are macronutrients, meaning that they are needed in larger quantities (Hochmuth et al., 2004). As the need for nutrients decreases, they are then measured in ppm, as opposed to percentages.

Table 1. Seventeen essential plant nutrients and the quantities in which they are found.

Element	Percentage Needed in Plants (Dry Weight)	Element	Amount Needed in Plants (Dry Weight)	Element	Amount Needed in Plants (Dry Weight)
Nitrogen (N)	2.0-5.0%	Sulfur (S)	0.2-0.5%	Molybdenum (Mo)	>1 ppm
Phosphorus (P)	0.25-0.60%	Iron (Fe)	0.5 ppm	Boron (B)	20-100 pm
Potassium (K)	>1.5%	Manganese (Mn)	20-100 ppm	Chlorine (Cl)	–
Calcium (Ca)	0.6-5.0%	Zinc (Zn)	25-150 ppm	Nickel (Ni)	0.5-5 ppm
Magnesium (Mg)	0.2-0.8%	Copper (Cu)	4-20 ppm	–	–

This can largely be attributed to the role that they play in plant cell growth and production. Nitrogen is a major component of chlorophyll and amino acids, while phosphorus is a crucial component to plant genetic material and therefore is also important for root and seed growth and development. Potassium has a more indirect role, but an equally important one. It serves as an activator to over 80 plant enzymes, meaning that functions are extremely limited if the presence of potassium is lacking (Potdar et al., 2020). If these nutrients are not at their respective optimal levels, then the ability of the soil to nourish and produce crops will be extremely limited.

The last major component of soil quality is biological, correlating with biota diversity and activity. Soil microorganisms influence a majority of the natural processes within soil that allow it to provide its environmental benefits, such as water quality control, absorption of greenhouse gasses, and the production of plants (Tahat et al., 2020). Even after they die, their residues make up 30-50% of organic matter (Hemkemeyer et al., 2021). Therefore, the maintenance of these microorganisms and their population is crucial to overall soil health. The soil microbiome is typically divided into two main categories: bacteria and fungi, because they are the two largest functioning microbial groups, and the ones that interact most in food webs (Buerkert et al., 2012). Bacteria are responsible for suppressing stressors like pathogens and pests, while also sequestering carbon and cycling nutrients (Bell et al., 2021). Fungi are responsible for the decomposition of organic matter as well as the delivery of nutrients for plant growth (Frąc et al., 2018).

Table 2. Ideal soil quality parameters for plant growth.

Soil Quality Characteristic Parameters	**Optimal Value For Productivity**	**References**
pH	6.0-7.5	Msimbira et al., 2020
Bulk Density	1.55-1.60	Diao et al., 2021
Soil Moisture	10-45%	Datta et al., 2017

Texture	Loam-textured	Diao et al., 2021
Nitrogen (N)	10-20 ppm	Marx et al., 1999
Phosphorus (P)	20-40 ppm	Marx et al., 1999
Potassium (K)	150-200 ppm	Marx et al., 1999
Organic Matter	3%-6%	Fenton et al., 2008

Urban Agriculture and Food Insecurity

Due to the global dispersion of different soil types and their various abilities to support crop growth, as well as a strongly established infrastructure, large-scale rural farming is not a productive option in all locations. As rates of land development grow, agriculture adapts in order to continue to serve human needs. Urban agriculture (UA), can be defined as “the growing of crops or raising of animals within and around cities” (Umesha, 2018). In recent years, (UA) has expanded, not only into a cultural method of land-use designed as a means to increase food access, but also as a source of environmental education, social cohesion, and recreation. This is especially true in impoverished areas, for those who rely on UA yield for sustenance, not just as an additive to their existing supply. The COVID-19 pandemic brought the vulnerability of global food supply chains to light after large-scale “panic buying” left grocery store shelves barren and unable to be fully restocked. The wide-spread shortages trickled into middle-class consumers who were not used to being denied resources. Because of this, there was a large-scale recognition of a modern lack of food security in urban communities, as well as a call towards the diversification of sources of food supply. These shortages were especially impactful for impoverished communities whose residents could not afford to buy multiples of necessary items (Langemeyer et al., 2021). The widespread increase of urban agriculture as a practice also offered additional resources to those who were especially vulnerable, as it offered an inexpensive opportunity to increase food supply oneself. More established urban farms also offer higher rates of their crop yield during troubling times in order to better support their communities. (Barthel et al., 2019).

Additionally, the cost for certain foodstuffs increases greatly when transportation over large distances is needed, because it requires more fuel. Food that travels large distances can also be referred to as "having more food miles" in comparison to those that may travel domestically (Hill, 2008). Long-term transportation also greatly reduces freshness, which is particularly critical for produce, which has a short shelf-life. There are much higher rates of food waste when traveling long distances is required, as it offers greater risk of food damage and spoilage. A centralization of food sources to those more local to oneself can greatly reduce the need for fuel, as well as the rates of food waste. For those who do not live in rural areas, one of the most convenient and accessible ways to do this is through urban agriculture, which is inherently centered in community support. Although it may not necessarily meet the needs of large-scale production, it offers an opportunity for additional resources in urban communities.

In order to meet the needs of yield, urban agricultural land would have to be increased in size. In comparison to the 1990s, the 2010s (particularly 2012-2015) had significantly lower rates of urbanization, particularly in residential space (Lathrop et al., 2016). As urban planning focuses have declined from residential areas, green spaces have captured attention as a priority. Not only do they offer ecosystem services such as climate control, they also offer great potential as food sources and educational opportunities (Semeraro et al., 2021). Allocating more of this green space towards urban farming is a simple, yet practical way to increase agricultural yield for the community. It would also allow for the seamless incorporation of hands-on educational programs, particularly focusing on the growing process and the importance of the incorporation of food with a larger nutritional profile. Not only do urban agricultural spaces serve the community as a food source, but they also offer the opportunity to make lasting positive change on an individual level. These spaces do not necessarily have to use precious ground space either, as there is great potential for the utilization of rooftop areas, which have generated successful yields and successful agricultural programs (Harada et al., 2020).

Even with small amounts of land, urban farms and community gardens have the potential to supply large quantities of nutritious food. For example, Brooklyn's *Added-Value* Farm produced roughly 40,000 pounds of food annually on just 2.75 acres, valued at approximately $100,000 USD. Camden, New Jersey, a city with only one full-service supermarket, harvested almost 31,000 pounds of produce at 44 sites (Royte, 2015). These farms offer tremendous opportunities and potential not only for community enrichment and education, but also for the supplementation of resources. Investing in these spaces not only provides more value to cities and urban spaces, which would technically be producing a profitable resource, but it would also greatly improve the quality of life in these areas, especially for those who are unable to continuously afford to buy commercial produce.

Food insecurity is a social issue that affects a variety of communities, and can be formally defined in the US as reduced quality, variety, or desirability of diet (USDA ERS, 2015). Americans are deemed food insecure if they did not have enough money to purchase enough or balanced meals, which offer a variety of micro and macronutrients, any time within the past 12 months (USDA ERS, 2016). Not only does insecurity include lack of access to sufficient quantities of food, but it also includes access to higher-quality resources, such as fresh produce. The average American has the right to outside support if they are unable to afford to sufficiently feed themselves and their families, and urban agriculture has the potential to greatly reduce the rate of food insecurity in the US. By offering under-supported communities access to fresh fruits and vegetables, it not only reduces consumer costs towards food, but increases the nutritional quality of their diet. This not only reduces the risk of health problems that may result from malnutrition, but can also lead to decreases in obesity rates, which are common in communities with high rates of food insecurity, especially in the United States (Parmar, 2023).

Sustainability, Sustainable Agricultural Practices, and Organic Agriculture

As urban development continues and the need for adaptation grows, it is important for the sake of successful longevity that the reactive changes being made can continue for long periods of time. For example, as urban landscapes grow and the need for urban agriculture does as well, it is important to have a full understanding of the effects of its implementation, as well as how to make positive change last long-term. The use of the term “sustainability” in much of scientific literature offers merely theoretical evidence, with little guidance on implementation strategies and outcomes (Moore, 2017). Using a comprehensive definition based on the wide scale analysis of scientific literature, sustainability can be defined as the continuous delivery of programs/strategies in addition to individual or program-wide behavioral changes that produce beneficial results over a given period of time (Moore, 2017). Before discussing the inclusion of sustainable practices to increase soil health, I believe that an important addition should be made to this definition. In order for a program/strategy to be sustainable, it should also cause minimal harm or damage to the health of the community. In this context, in order for a program or method to be sustainable, it must induce behavioral changes within a community and yield a form of beneficial result, which will almost always include foodstuffs. It must also cause minimal harm to the surrounding environment, particularly soil and water systems. In summary, a program may be sustainable if it causes greater good than harm for both communities and environmental systems.

When discussing agricultural sustainability, it is crucial to acknowledge its origins, which are largely rooted in indigenous methods and practices. In the Northeastern United States, the Lenni Lenape people were the ones who originally cultivated the land. The Three Sisters practice encourages the usage of companion planting in order to gain mutual benefits from each system, and is an example of a practice created by the Lenni Lenape people (Holmes, 2022). They also often operated on a no-till or low-till system, and cultivated exclusively through the use of hand tools. One of their main focuses in agriculture was working in conjunction with the earth, and allowing its natural systems to nourish the crops. Post colonization, these practices have been adjusted to better suit a more populated and industrialized world, however, their original means remain the same. What once belonged to the Lenni Lenape people is now labeled as "sustainable", and has become increasingly popular on a global scale. After centuries of attempts to seriously industrialize agriculture, there is a reversion towards more natural practices. Although this is not inherently bad, it is incredibly irresponsible to make this shift without acknowledging the source of such successful sustainable practices.

Agricultural sustainability is the ability of crop production to continuously produce food without environmental degradation (Tahat et al., 2020). These practices affect various aspects of soil health and farm systems, and the combination of these methods may look a bit different depending on climate and crop type. However, there are certain techniques that are becoming increasingly standardized due to their high rates of success. These include but are not limited to: low till/no till systems, the usage of organic fertilizers, and cover cropping.

Minimalizing tillage in agricultural spaces minimizes the damages that are done by long-term conventional tillage, the most prevalent of which is soil compaction. Compacted soil not only affects the physical properties of a soil, but it also reduces the transport of water and growth of plant roots (Yang et al., 2021). These factors indicate that tillage not only reduces soil health, but it also greatly reduces potential crop growth and yield. It also greatly disrupts the soil microbiome, and can damage their population and activity within the system. Although occasional tillage at the surface level can aerate the soil and assist with the breakdown of organic matter, integrating a low till or no till system would be much more efficient and beneficial long-term.

In the late 1960s, there was a strong global attempt to increase crop production, which was done through a variety of means. Known as the Green Revolution, the movement consisted of multiple changes to standard agricultural procedures such as: increased farm area, the planting of two annual crops rather than one (double-cropping), adoption of high-yielding varieties (HYV) of seeds, improved irrigation, as well as the increased use of synthetic pesticides and fertilizers. The impact was seen very strongly in India, which grew to be the largest producer of pesticides in Asia as a result (Narayanan et al., 2016). Although the Green Revolution aimed to alleviate agricultural burdens of feeding a growing population and reduce hunger, it increased the usage of modern machinery and synthetic fertilizers, which caused much more damage than anticipated. Although the use of synthetic agro-chemicals can sustain short-term productivity, their use over longer periods of time reduces fertility and jeopardizes the success of soil biota and other natural processes (Bhunia et al., 2021). The use of these chemicals also pose a threat to human health, particularly through what is known as "pesticide suicide." In this circumstance, the consumption of pesticides is the cause of death. It is especially popular in India, which has the highest rate of farmer suicides (Prasad, 2016). They are also simply harmful to ingest in large amounts, which is not uncommon, as they are being used directly on foodstuffs (Karunarathne et al., 2020). In India, there was an increase in crop production for roughly 20 years, until yield became stagnant and began to drop. The growth rate in the output of cereals dropped from 2.76 percent in the 1980s to 1.25 percent in the 2000s (Jain, 2018). The Green Revolution left a strong impact on agriculture, as it eventually reduced crop yield and created more human health and exposure risks. It also left land with higher rates of salinization and mineral weathering, greatly reducing the amount of productive farmland worldwide (John et. al 2021). India has had to greatly invest in the remediation of their farm soils in order to maintain yield demands for the country. Although soils have the potential to be remediated, it requires much more time and greater resources than that of sustainable, organic techniques and technologies. Organic agriculture, also known as organic farming, targets equilibrium in soil dynamics without the usage of synthetic fertilizers. Oftentimes, organic fertilization consists of the usage of animal wastes, which offer a balanced supply of carbon, nitrogen, and phosphorus as well as a large variety of micronutrients. It also accumulates greater soil organic matter (SOM) and enhances the cohesion of aggregates. It is important to note that animal wastes that are sourced from slaughterhouses are not at all the same as fecal matter. Slaughterhouse wastes typically are high in heavy metals, and have been shown to negatively affect soil biota. Adversely, the long-term use of fecal-sourced fertilizers has been shown to promote microbial abundance, provide micronutrients to soils, and protect crops from soil-borne pathogens (Bhunia et al., 2021). Organic fertilizers increase quality food production without compromising soil fertility long-term, and the usage of animal wastes additionally offers a sustainable disposal solution, as it promotes a circular bio-economy.

In addition to the use of organic fertilizers, cover cropping can also produce beneficial results. It is defined as the usage of any sort of crop to cover the soil, in addition to the growth of the main crop. There are circumstances where the cover crops themselves may be harvested, but this is uncommon, as their main purpose is simply to cover the soil. The benefits of this technique have shown to be extensive, particularly in large, monocropped areas. There are two main types of cover cropping: legume and non-legume. The former consists of leguminous plants, such as alfalfa and clover, while the latter consists of non-leguminous plants such as barley and oats. Each type offers advantages in some way, but the success of their usage would depend greatly on the needs of the soil. For example, legume crops were shown to be more successful at supplying nitrogen, while non-legume crops were shown to be more effective at enhancing the SOM (Muhammad et al., 2021). However, in comparison to soils with no cover crop, both types were shown to increase soil bacterial and fungal colonies, microbial biomass, and phospholipid-derived fatty acids. Structurally, cover crops increased root colonization and reduced erosion. Medium-textured soils showed the greatest response to the benefits of cover cropping. Generally speaking, cover crops protect soil from overexposure to natural conditions (precipitation, sunlight, etc.) and have been shown to enhance soil health through microbial community in comparison to soils with no cover crop. In a recent meta-analysis by Kim et al. 2020, the analysis of 60 studies demonstrated a 27% increase in microbial abundance, a 22% increase in microbial activity, and a 2.5% increase in microbial diversity as a result of cover cropping. The studies were chosen for the analysis to create a diverse range of agricultural conditions, as well as interactions with cover cropping. Based on the analysis of all 60 studies, it was shown that cover cropping generally increases abundance, activity, and, to a lesser extent, diversity (Kim et al., 2020).

Lastly, organic farming is defined as the cultivation of agricultural products without the use of synthetic chemicals or fertilizers. It is common to use animal wastes as a form of fertilization, and it is widely considered to be a more efficient use of environmental resources in comparison to conventional farming (Smith et al., 2019). Although organic farming has the potential to increase variability in agricultural yield, it has also been shown to reduce soil erosion and aquatic ecotoxicity (Azarbad, 2022).

Grow It Green

Grow It Green (GIG) is an organic, urban farm located in Morristown, New Jersey. It is a one-acre property known for its sustainable agricultural processes as well as its significant engagement within the community. Although they do sell a fair amount of their produce, they also offer a significant portion to help support food insecurity within their community. As an organization, GIG annually donates over 20,000 pounds of food to local organizations so that it can be distributed to those in need, making it a paramount resource for the New Jersey community. In order to continue this work, the farm must be maintained properly so as to keep up a high yield, so that they have enough produce to sell but also to give away. As soil is heterogeneous, there is not a uniform distribution of its resources. Soil quality is determined by a wide range of factors, which all need to be considered when designing sustainable systems to improve overall soil health.

Objectives of This Study

The purpose of my research project is to study how urban farming affects soil quality and health. This study is the first of its kind to be conducted at GIG, meaning my research provides baseline data for the site which can be used not only as a future reference point, but also a guide on what can be done to better suit their land and support their agricultural practices. I hope that providing an overview of these factors will allow GIG to better plan their growth and appropriately allocate their resources so as to improve upon their contribution to the community.

On a larger scale, I hope that my investigation of sustainable agricultural practices will shed light on their potential successes, both ecologically and economically. The incorporation of these techniques on a greater scale has the potential to yield the same, if not more crop yield without sacrificing soil health and ecology. As the global population grows and more land is used for building and development, it is crucial that we as a society allocate resources as efficiently as possible without sacrificing any quality of life. The investigation of *Grow It Green* as a case study not only offers data on the benefits of sustainable, organic farming practices, but also showcases the community and educational benefits of urban agriculture.

Methods

Site Selection

The testing sites were all located on the property of *Grow It Green* in Morristown, New Jersey (Figure 6), which is an organic urban farm. This site was chosen for many purposes, the primary one being the observation of its unique agricultural practices. The farm is located on previously unused land which is leased from Morris County, but originated from the possession of the Lenni Lenape people. The maintenance techniques are rooted in indigenous growing methods, as most of the land is worked by hand, and there is a strong focus on a low till/no till system. They also practice companion planting, so that crops can receive benefits from multiple sources. The farm itself is split into nine different blocks, labeled A-I. Although testing was not conducted on every block of the farm, the blocks that were selected offered variety in the testing group in at least one category: location, size, and crop type. The sites were also selected based on which ones were actively in a growing season, as some of the blocks were freshly cleared in order to prepare for future planting. No blocks were selected if they were underneath a tunnel in order to maintain consistency with the exposure conditions. All of the sampling was conducted on various blocks of the farm, as well as an undisturbed area to be used as a control. Lastly, the urban farm is located within a five mile radius from the Drew University campus, which offers accessibility, not only for research purposes, but also as a means for Drew University students to obtain local, organic produce and gain exposure working with sustainable agriculture techniques.

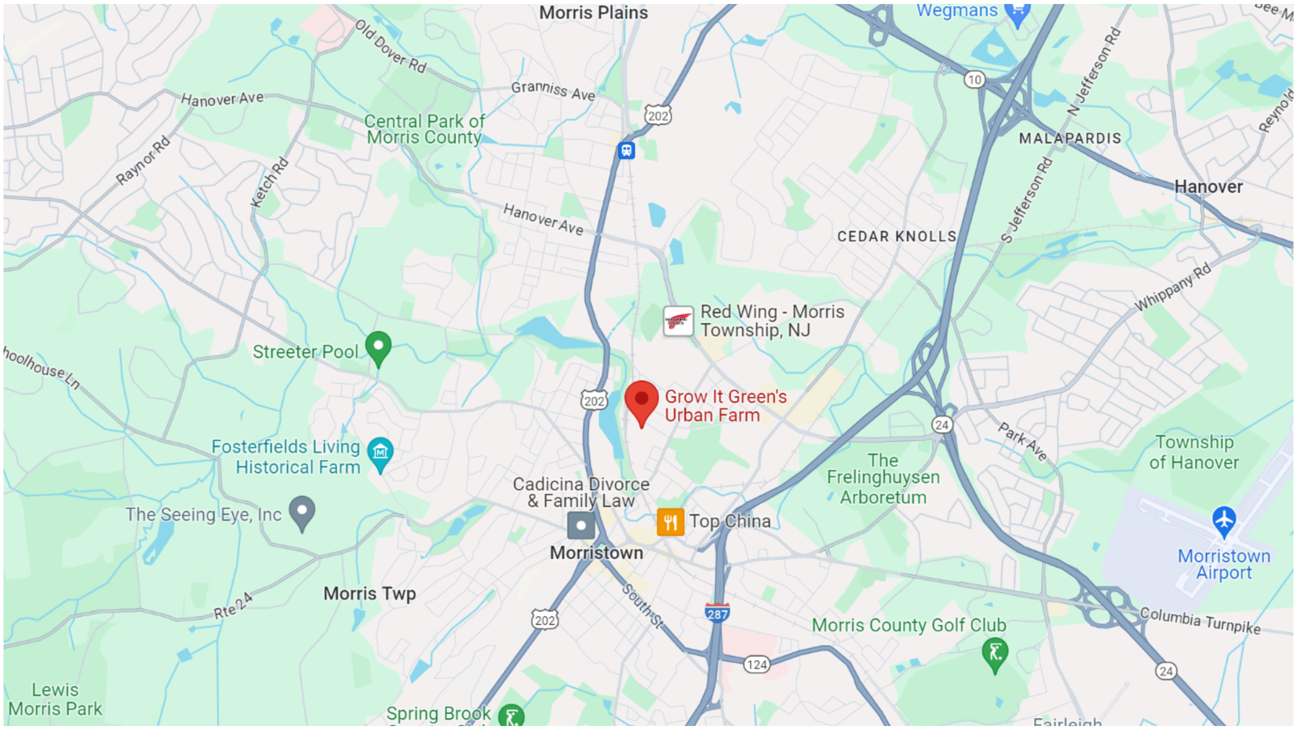

Figure 6. A view of the GIG location in relation to the Morristown, NJ area (Google Maps, 2024).

Figure 7. An aerial view of the GIG sampling sites, using information from the ArcGIS online database.

Field Data Collection

Before collecting soil samples from any of the sites, I obtained permission from the Director of Agriculture Shaun Ananko. I collected all soil samples at the same time of day, from 11 am to 12 pm. Additionally, all of the samples were collected within the same agricultural season. For each area sampled, I would include soil from five different points, with at least one in each bed. The soil was then combined into one bag to obtain composite samples of each block.

The soil was collected from roughly six inches below the surface, because it more accurately reflects the soil type around plant roots, as well as the resources that are available to said roots. It was not collected from footpaths or any other areas of heavy traffic. The samples were collected using a standard garden trowel and were stored in plastic Ziploc bags. The trowel was cleaned in between sampling to reduce cross contamination, and fresh bags were used every time. There are five sampling areas, meaning that there was a grand total of 25 sampling points. One area is used as a control, which is a stretch of land still located on the farm property but does not receive any treatment to aid in cultivation (fertilizing, tilling, etc.). It contains native plant species but it is not used to contribute to the farm's annual yield. A control was included so as to offer data regarding the parameters of the naturally occurring soil in the area, so as to better compare the agricultural blocks. Essentially, the control is used as a basis for comparison for the effects of GIG's management practices, as well as a common denominator for any significant variation that may occur between blocks themselves. GIG consists of nine total blocks, which vary in the amount of beds per block. Four out of the nine blocks were used for sampling, C, F, H, and I (Fig. 3). The crops cultivated in each block are as follows: kale/rainbow chard, lettuce/cabbage/napa cabbage, bell peppers/shishito peppers, and skinny eggplant, respectively.

While collecting from each point, I used a handheld UNSM41 Soil Meter to measure pH as well as soil temperature. The values were obtained from each of the five points within the block, and then averaged. It is important to note that the handheld probe only offers values with two significant figures, so the data that was obtained with this method is used to support the values that were obtained from further lab testing. Soil samples were also collected for bulk density study in soil cores.

The soil sample was air-dried, passed through a 2 mm sieve and homogenized prior to lab analysis. For the pH and microbial study, the soil samples were stored in the refrigerator at 4℃ in the Drew University Soil lab, which is the temperature below which there are no changes to soil properties.

Soil Analysis

Under the supervision of Dr. Shagufta Gaffar, I conducted a variety of tests on the soil samples to determine selected physical, chemical and biological properties of the soil.

Soil Physical Properties

Bulk Density

Bulk density (BD), defined as the ratio between the mass of soil to the bulk volume of soil, was calculated as:

$$BD = \frac{oven\ dry\ weight\ of\ soil}{bulk\ volume\ of\ soil} \quad \text{...}(1)$$

The bulk volume of soil is obtained from the volume of soil cores which is equal to $\pi r^2 h$.

For this test, soil cores were collected from each of the testing blocks and left in an oven to dry (Figure 8).

The oven temperature was 105℃ and the samples were left in there for 24 hours before being weighed. There was only one sample for every block, totaling five samples. The results are presented in Figure 10.

Figure 8. Soil cores in the oven as per the measurement of soil bulk density.

Porosity

Porosity, defined as the ratio between the bulk density and particle density of soil, was calculated as:

Porosity (%) = 100 - $\left(\frac{Bulk\ Density}{Particle\ Density}\ X\ 100\right)$……………………..……………………………(2)

Moisture Content

Soil moisture content, defined as the ratio between the mass of wet soil to the mass of oven dry soil, was calculated as:

Moisture content (%) = $\frac{mass\ of\ wet\ soil - mass\ of\ oven\ dry\ soil}{mass\ of\ oven\ dry\ soil}\ X\ 100$ ……………………………….(3)

The soil moisture content was measured by leaving samples in the oven for 24 hrs at 105 °C. Three replicates were created for each block, adding up to 15 total samples. The results are presented in Figure 10.

Soil Texture

Soil textural class was analyzed by the hydrometer method using a Fisher brand ATSM152H soil hydrometer. Using five 1000 mL graduated cylinders, one trial was conducted for each sampling block (Figure 9). All trials were conducted simultaneously in order to ensure consistency of conditions. The original mixture consisted of 40 g of

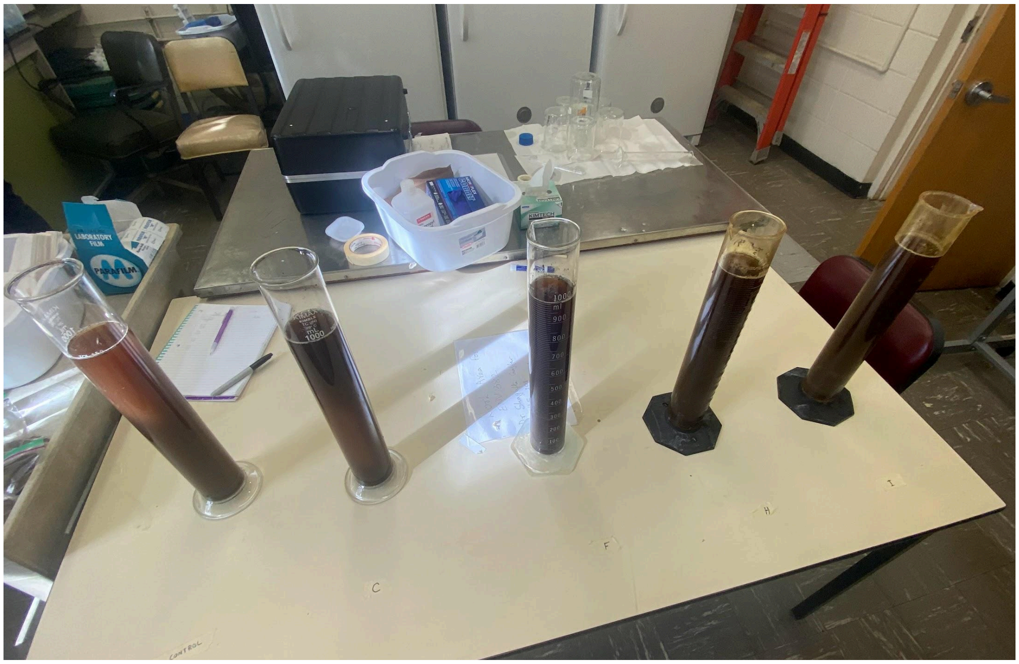
Figure 9. Hydrometer method lab setup.

air dried soil and 100 mL of a sodium hexametaphosphate solution, after which the cylinder was filled up to the 1000 mL mark with tap water. They were then mixed thoroughly by covering the top with parafilm and carefully inverting the cylinder. Immediately after mixing, the hydrometer was added to the cylinder placed on the benchtop and a timer started. A reading was recorded after 40 seconds in order to determine the sand content, and then again at the two hour mark in order to determine the clay content. The silt content was determined from the differences of sand and clay content from the soil. Let it be known that the trials were conducted with allocated time between them so as to allow for the appropriately requested timing for each one. The hydrometer was also cleaned thoroughly between each trial so as to limit contamination. The results are presented in Table 4.

Soil Chemical Properties

pH

Soil pH was measured in a 1:2 (w/v) soil/deionized (DI) water mixture using a LabQuest testing probe. In order to conduct this test, I created slurries with five grams of soil and ten mL of DI water. I ran a total of three replicates for every block, yielding 15 samples all together. After the slurries were created, they were left to sit for 30 minutes to allow for the particles to settle to the bottom. The pH probe was calibrated at the beginning of the test, and cleaned thoroughly with DI water between each use. The values were then recorded and averages for each block were calculated (Table 5).

Soil Organic Matter (SOM)

The organic matter (OM) content was determined by the loss on ignition (LOI) method with a Fisher Scientific muffle furnace (at 500 °C). Three replicates of each block were used, totaling 15 samples. For each sample, five grams of the air-dried soil was put into a crucible cup, then placed into the muffle furnace at 500℃ for five hours before it was switched off and left overnight to cool. The cup was then weighed in order to measure the difference. Due to the size of the oven, only six cups were able to fit into the oven at one time, so the trial took place over a series of roughly four days. The organic matter was calculated as,

$$\text{OM (\%)} = \frac{mass\ of\ soil - mass\ of\ oven\ dry\ soil}{mass\ of\ soil}\ X\ 100 \ldots\ldots(4)$$

The results are presented in Table 5.

Soil Nutrients

The soil samples were tested for the three key soil macronutrients: nitrogen, phosphorus, and potassium using LaMotte soil testing kits. In order to determine the nitrogen, a test tube was filled with Universal Extracting Solution and two grams of dried soil. The substances are mixed and then filtered through filter paper into a clean test tube. One milliliter of the soil extract was then transferred to the spot plate, which is a small, white, ceramic plate with an intent to hold liquid. The soil extract was then mixed with ten milliliters of Nitrate Reagent #1 and 0.5 grams of Nitrate Reagent #2. After mixing, the color of the resulting solution was compared to the given color chart in order to determine the nitrogen content in pounds per acre. To measure the phosphorus content, a test tube was filled with Universal Extracting Solution, as well as two grams of dried soil and mixed. It was then filtered through filter paper into a clean tube, where six drops of Phosphorus Reagent #2 and one Phosphorus Test Tablet were mixed with it. After mixing until the tab disintegrated, the color of the solution was compared to the given color chart. It is important to note that all color comparisons were done in natural light, as directed by the instructions. Lastly, to measure the potassium content, a test tube was filled with Universal Extracting Solution and two grams of dried soil. After mixing, it was filtered using filter paper. A clean test tube was then filled to the given line with the soil extract, which was then mixed with a Potassium B tablet and Potassium Reagent C. Then, the clean measuring tube was placed onto the reading plate, which is a small white plate with a thick black line through the middle. In order to determine the results, the solution is added to the tube until the black line disappears while looking down from the top. If it does not disappear, it is assumed that the potassium content is lower than 100 pounds per acre. Results are presented in Table 5.

Additional lab tests for the nutrients were performed in order to generate more accurate results. The nitrogen test began by mixing one gram of soil with 10 mL of the extraction solution (potassium chloride, KCl), mixing, then filtering the solution through Whatman 42 filter paper. Then, five mL of the soil extract was mixed with a pinch of Fisher G Carbon Black, and filtered again. After adding appropriate reagents, this solution was then measured using a spectrometer, along with nine standard solutions in order to provide a framework for reference. Three replicates were measured for each sampled area, totaling 15 measurements in addition to the standard solutions. A similar procedure was conducted to determine the phosphorus content, as one gram of soil was mixed with 10 mL of extraction reagent (sodium bicarbonate, $NaHCO_3$), and then mixed. Afterwards, the solution was filtered into clean tubes, where five mL was used to create the working solutions. Because of low product creation, only three mL were used. Additionally three mL of DI water and three mL of color developing reagents were added, then left to stand for 15 minutes before reading in order for the foaming to subside. Similarly to the nitrogen test, three replicates were created for each sampled area. The same procedure was conducted for nine standard solutions. Despite the conduction of these experiments, the data was not usable for statistical analysis. The spectrometer readings for the nitrogen test were negative, and therefore unusable, and the phosphorus readings were unable to generate a standard curve.

Soil Microbial Properties and Enumeration of Soil Microbial Populations

Bacterial and fungal population in soil were studied following the modified dilution spread plate microbial colony count method (Bey, 2001).

In order to measure the bacterial and fungal colonies for the samples, two different types of microbial plates were created. For the fungal colonies, corn meal agar (CMA) was used and the samples were plated at a 10^{-4} dilution. The initial bacterial colonies were plated using tryptic soy agar (TSA) at a 10^{-6} dilution, which did not yield accurate results. In order to obtain more accurate data, another trial was conducted using the antifungal agent cycloheximide as well as a 10^{-4} dilution. All of the mediums were created according to the ratios provided on the containers, autoclaved, and distributed into sterile petri dishes. For the plating itself, test tubes and DI water were autoclaved, and the station was sanitized using alcohol. For all trials, one gram of the soil sample was mixed with nine mL of DI water in an autoclaved test tube. The contents were mixed using a Vortex Genie mixer. One mL of the mixture was measured using a pipette, then added to a different test tube, and mixed with 9 mL of DI water, resulting in a 10^{-2} dilution. The steps were repeated according to the appropriate instructions for each dilution. Let it be known that new pipette tips were used every time, and that a burner was lit the entire time of plating in order to reduce airborne contamination. There were three replicates for each block, totally fifteen samples for each type of colony and 30 plates in total. The plates were kept in separate drawers for incubation before counting. Typically, plates containing 30-300 colonies were counted manually after 24 hours of incubation at 28°C for bacteria and after seven days for fungi (Bey, 2001). The plates were monitored over the next four days (totaling two weeks) in order to ensure adequate colony growth, as well as no major changes or instances of contamination. The colony forming units (CFU) were calculated using the following formula:

$$\text{CFU/gm soil} = \frac{number\ of\ colonies\ X\ dilution\ factor}{volume\ of\ culture\ plate\ (ml) X\ dry\ weight\ of\ soil\ (gm)} \quad \text{......................................(5)}$$

Results are presented in Figure 11.

Plant Parameter Analysis

The selected plant parameter was yield (lb), which was measured as the weight of crop after harvest. Over four different blocks, the following crops were harvested: kale, rainbow chard, napa cabbage, green cabbage, lettuce, watermelon radishes, skinny eggplant, bell peppers, and shishito peppers. In order to measure plant yield, each harvest was weighed and recorded. This data is also collected by *Grow It Green*, and is used to calculate their annual yield. The sampling period for yield is from September 1st to October 31st, in order to keep consistency. It is important to note that different crops have different growing styles, as well as different sizes and weights when fully grown, which may contribute to any significant differences. The blocks do also vary in size, which affects how much can be planted at one time.

Limitations of This Study

Because of the time constraints of this study, not all agricultural blocks at *Grow It Green* were able to be sampled, meaning that the overall results are more of a generalization of urban agricultural soils. A continuation of research specifically at the GIG site could include sampling and testing in blocks A, B, D, E, and G. Additionally because of the time constraint, the period in which harvest was measured was minimized, which is especially influential because of the growing seasons for specific crops. The sampling period may not have been the most fruitful time of year for certain blocks, which gives the illusion that they are underproducing. The plant yield data could be enhanced by a lengthened sampling period. Although GIG regularly collects harvest data, a harvesting observation period was established in order to provide consistent results, and because the timing correlated directly with the timeline of the soil research. Because this is the first study of its kind conducted at GIG, providing the most up-to-date information was also a factor. The lab procedures were also limited by experimental errors possibly due to reagents, particularly with the UV Vis spectrophotometer there was error generating the standard curves for the nitrogen and phosphorus determination. Data for potassium determination also could not be generated as the torch for the ICP-OES shut down several times. Therefore, the nutrient data that was generated only using a test kit was used in this study. This study could be furthered by the generation of more accurate and precise nutrient data using lab instrumentation.

Statistical Analyses

Data were presented as means with standard errors. Statistical analysis was performed using the statistical analysis system IBM SPSS Statistics 28. One-way Analysis of variance (ANOVA) was carried out for the effects of different blocks on soil physical properties, chemical properties, microbial population and crop yield. Tukey–Kramer post hoc tests were performed to compare mean separation at $p < 0.05$ among blocks. Any differences between the mean values at $p < 0.05$ were considered statistically significant. Two-way ANOVA without replications was performed for the effects of different blocks, crop type and crop yield. Pearson multiple correlation coefficient analysis was conducted to show the relationship among all the parameters.

Results and Discussion

Physical Properties

In order to study the quality of the soil's physical properties, certain characteristics were measured. They are presented and discussed in Tables 3 and 4, as well as Figure 10.

Table 3. The *p* values for the effect of different blocks on the physical properties of soil.

Sources of Variation	Moisture	BD[§]	Porosity
Block	0.005*	-	-

[§]BD= Bulk Density, * = Significant at $p < 0.05$; Values not included were not significant.

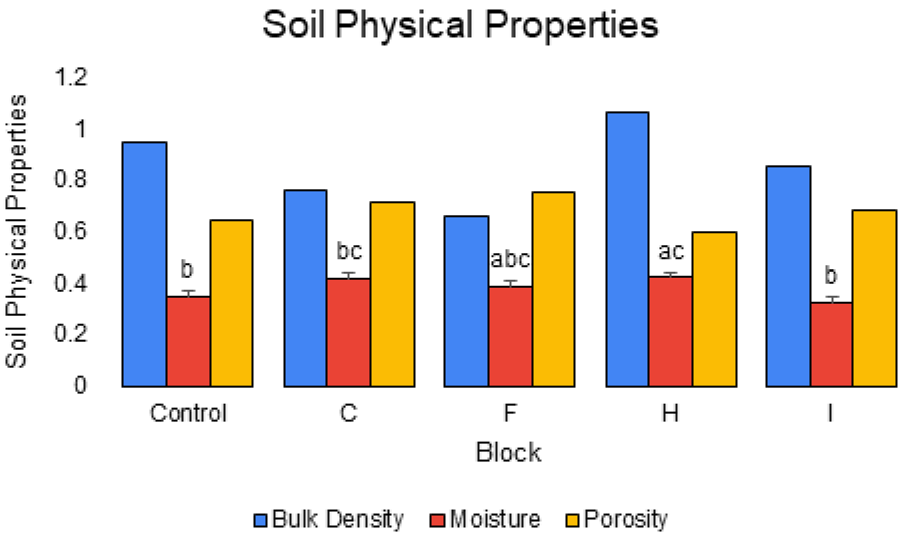

Figure 10. Soil physical properties of the different blocks; similar letters indicate not significantly different at p<0.05.

The bulk density value is a measurement of the weight of powder, which in this case is expressed as g/㎤ whereas the porosity value is a measurement of the percentage of void space, and is typically expressed as such. It is expressed as a proportion in Figure 10 in order to allow for an accurate comparison between all of the physical components. The typical bulk density for sandy loam and loamy sand soil types ranges from 1.55–1.60, meaning that the values obtained in this trial are overall very low. Having a low bulk density is considered to be very good, because it will allow for good water and air retention, thus maximizing plant growth. All of these sampling areas also had high porosity rates (over 50%), indicating that there is great potential for water infiltration, biological activity, and root growth. The bulk density value obtained was also used to calculate the porosity, which refers to the amount of open space between soil particles. Porosity ranged from approximately 0.59 to 0.75, which were all on the higher side of the standard range of 0.3 to 0.7 (Diao et al., 2021). As opposed to bulk density, a high porosity value indicates ample space between soil particles, which allows for better water and air filtration and retention.

Additionally, it further supports cultivation by providing space for the growth of plant roots.

The moisture content in this experiment was calculated using the gravimetric water constant method, which can be explained as the ratio of water to soil. Therefore, the values being expressed are the grams of water within a gram of soil. A healthy soil moisture content ranges from 10% to 45%, under which all of the sampled values fell. Additionally, all of them fell on the higher side of the range, indicating higher water retention rates. Having a high retention is beneficial because it provides an ongoing supply of available water to plants. Even if soil has enough water to continue its standard functions, it will not benefit crop growth in any way if there is not a high enough quantity that is usable to plants.

Table 4. The textural classification of each block.

Block	**Sand**	**Silt**	**Clay**	**Classification**
Control	67.5%	22.5%	10.0%	Sandy Loam
C	70.0%	20.0%	10.0%	Sandy Loam
F	72.5%	17.5%	10.0%	Sandy Loam
H	77.5%	12.5%	10.0%	Sandy Loam
I	82.5%	10.0%	7.50%	Loamy Sand

The texture of each testing area was relatively similar, with the only difference in classification falling in Block I. As shown in Figure 5, the two classifications fall directly next to each other, and are closely related. Although there is technically a difference in classification, the values do not showcase any significant differences or areas of concern. The soil texture remains relatively consistent throughout all of the sampling areas, with the exception of Block I. This is likely due to a variety of factors, mainly due to the fact that the crop being cultivated in that area was skinny eggplant at the time of sampling. This is significant because eggplant prefers sandy soils for maximum productivity. Additionally, Block I was towards the end of the growing season at the time of sampling, meaning that it would have been more exhausted of certain parameters. Despite these factors, there was still little deviation regarding soil texture, as well as significant crop yield, which indicate that the soil was not under substantial environmental stress.

Chemical Properties

Similarly to the physical properties, certain characteristics were measured in order to determine the overall quality of the chemical properties of the soil. They are presented and discussed in Tables 5, 6 and 7.

Table 5. Soil chemical properties for each sampled area.

Block	pH	OM[¶] (%)	N (ppm)	P (ppm)	K (ppm)
Control	7.25±0.10[a]	10.40±0.59[b]	50	100	<100

C	6.87 ± 0.13^{b}	24.00 ± 1.32^{a}	15	175	<100
F	7.01 ± 0.11^{c}	16.80 ± 0.26^{bc}	60	150	105
H	7.13 ± 0.15^{acd}	15.13 ± 0.55^{bcd}	50	150	<100
I	7.17 ± 0.12^{ad}	13.40 ± 0.54^{bcde}	15	150	<100

¶ OM= Organic Matter. Values are expressed as mean ± standard error; means within a column followed by the same letter are not significantly different at $p < 0.05$.

Table 6. The *p* values for the effect of different blocks on the chemical properties of soil.

Sources of Variation	pH	OM¶	N	P	K
Block	<0.001*	<0.001*	-	-	-

¶OM= Organic Matter; * = Significant at $p < 0.05$; Values not included were not significant.

The pH for the soil was obtained using two different methods: the usage of a handheld probe during the sampling process as well as a laboratory pH meter. Because of the increased accuracy and precision of the laboratory pH meter in comparison to the field probe, the lab values were the ones utilized for the analysis. Since all of the values fall within the range of slightly acidic (6.1-6.5) to slightly alkaline (7.4-7.8), agricultural productivity is still possible. In comparison to the control, all of the blocks had a slightly lower average pH, but no values fell out of the neutral range, meaning that agricultural productivity is possible in all blocks. As shown in Table 5, block C yielded the lowest value, which was still well within the ideal range, even though it was not statistically similar to any other sampled area. In comparison to the control, only blocks H and I showed statistical similarity. In comparison to each other, the control, block C, and block F showed no significant statistical similarities, while block H was statistically similar to all other sampled areas except for block C, and block I was statistically similar to the control and block H. The variable pH values between the control and different blocks can be attributed to multiple factors. Although each block receives the same type of fertilizers, there is an uncontrollable lack of uniformity between them which may be the source of certain changes. For example, even if all blocks are treated with the same amount of chicken manure, there is no guarantee regarding the amount of nutrients and organic matter within each piece of manure. The overall quantity of organic matter may also be affecting the pH, as shown in Table 6. It is also evident through the evaluation of data for block C. A high organic matter content may lower the pH of the soil because its decomposition will result in higher quantities of organic acids. Block C showcased the highest SOM content and the lowest pH. Although all blocks are treated with the same organic fertilizers, crop discards are left in the field to decompose. Because block C contains the leafy vegetables such as kale and rainbow chard, they are more heavily pruned before processing, which would technically be supplying the block with a greater amount of organic material in comparison to a block that cultivates non-leafy crops that do not require heavy pruning, such as bell peppers or skinny eggplant. Because this study is the first of its kind to be conducted at GIG, and because pH is so intertwined with other chemical characteristics of soil, it is difficult to determine which specific parameter is the biggest source of change.

The nitrogen values for the test kits are measured in ppm, and were assigned based on their placement on a given color chart. A value was assigned based on the closest match to the given color choices, which ranged from 10-150 ppm. Although this does leave more room for error, it is not altogether dismissable. This test-kit method is typically used more in the context of field work, but that does not necessarily mean that the results are invalid for discussion. As shown in Table 5, the nitrogen content of the control was approximately 50 ppm, which is already higher than the standard 10-20 ppm (Marx et al., 1999). Blocks F and H had similar values, showcasing 60 ppm and 50 ppm respectively. All of these high values may be attributed to experimental error, however, they may also be linked to the high fertilization that the soils receive. All of the added organic matter, particularly the chicken manure, contain irregular nutrient quantities, meaning that different blocks may be receiving different amounts. This is also probable due to the significantly lower nitrogen quantity in blocks C and I, both of which showcased values around 15 ppm. It is also important to note that these blocks were deeper into their harvesting stages at the time of sampling, which means that more nutrients may have been uptaken by plant matter. Although the values are technically lower than the rest of the sampled areas, they still fall within the healthy range of soil nitrogen quantity.

Similar to the nitrogen values, the phosphorus values for the test kits are measured in ppm, and were assigned based on their placement on a given color chart. A specific value was assigned based on the closest match to the given color choices. Even accounting for potential error that may have resulted from the subjectivity of the color distinguishment, the phosphorus content was extremely high in comparison to the ideal 20-40 ppm range. As the soil parameters are intertwined with one another, this high concentration may have multiple reasons behind it. As shown in Figure 11, the fungal population in certain blocks was higher than that of the control. A high fungal population is helpful in supplying phosphorus and increasing its availability (Padje et al., 2020). It is most available to plants when the soil falls within a pH range of 6.0 to 7.0 (Jeschke, 2017), which is the case for nearly all of the sampled areas. Additionally, the blocks are treated annually with mushroom compost, which is technically supplying additional fungal colonies to the soil, thus encouraging a positive feedback loop between phosphorus availability and a strong fungal population.

The potassium values for the test kits are measured in ppm. Because most of the sampling areas yielded a range as a result as opposed to a specific value, this does reduce some of the precision among the analysis, but, once again, the results are still valid for discussion and analysis. None of the sampled areas resulted in values within the optimal 150-200 ppm range (Marx et al., 1999). Low potassium may be caused by a wide variety of factors, including poor aeration and/or drainage, high soil pH, and improper irrigation (Costello, 2003). Because of the low bulk density and high porosity values, it is unlikely that any potassium deficiency can be attributed to any issues with irrigation, aeration, or drainage. Although the pH for four out of the five sampled areas was over the neutral 7.0, they are still not considered to be within the “high” pH range. Because the potassium values for the control were also less than 100 ppm, it can be assumed that the region has a naturally low potassium content to begin with. All of the fertilizers used at GIG are complete fertilizers, meaning that they contain a variety of nutrients, but they do not necessarily have an ideal mix for the needs of this particular soil. Because of the high quantities of nitrogen and phosphorus, and the extremely low quantity of potassium, it is recommended that the farm substitutes one source of complete fertilizer for one specifically rich in potassium, such as potassium chloride or potassium sulfate.

Healthy rates of SOM in agricultural soils range from 3% to 6%, meaning that the soil at *Grow It Green* is significantly high in organic matter content. However, even with values so high, soil health and quality are not at risk unless there is a change to the pH that would cause harm. Higher organic matter content usually leads to soils with a lower pH due to the creation of organic acids, however, the optimal soil range already skews slightly lower, meaning that there is less chance of soil harm. As seen at *Grow It Green*, Block C demonstrated the highest SOM content out of all of the testing areas, and also had the lowest pH. However, because the pH still fell within the optimal range, there was no significant effect observed for the other parameters or the crop yield. The high rates of organic matter at GIG can be attributed to multiple factors. Firstly, the farm operation itself is organic, thus the only fertilization would come from biological sources. Each block receives mushroom fertilizer annually as well as chicken manure after seeding. The chickens are raised on the property, which offers a regular supply of organic fertilizer. After pruning, harvesting, and clearing, the crop scraps are left to decompose on top of the soil, offering another source of organic enrichment. Additionally, the farm practices cover cropping, typically with clover, which is a legume form of cover crop. The clover helps to prevent soil erosion and nutrient runoff, in addition to capturing excess nutrients after a crop is harvested.

Table 7: Pearson's multiple correlation coefficient values for the relationship between soil physical and chemical properties.

	Moisture	BD[§]	Porosity	pH	OM[¶]	N	P	K
Moisture	1	-	-	-0.59*	-	-	-	-
Bulk Density	-	1	0.96**	-	-	-	-	-
Porosity	-	0.96**	1	-	-	-	-	-
pH	-0.59*	-	-	1	-0.85**	-	-0.89*	-
OM	-	-	-	-0.85**	1	-	0.88*	-
N	-	-	-	-	-	1	-	-
P	-	-	-	-0.89*	0.88*	-	1	-
K	-	-	-	-	-	-	-	1

[§] BD = Bulk Density; [¶] OM = Organic Matter; *=Correlation is significant at the 0.05 level; **=Correlation is significant at the 0.01 level; Values not included were not significantly correlated.

Table 7 demonstrates the statistically significant correlation between certain physical and chemical soil parameters. While correlation at the 0.05 level is considered to be statistically significant, correlation at the 0.01 level is considered to be highly statistically significant. At the 0.01 level, bulk density and porosity were significant. This is likely due to their strong inverse relationship. These two parameters affect each other greatly. For example, as previously demonstrated, the porosity values were calculated using the bulk density data. If a soil has a low bulk density, then it must have a high porosity, and vice versa. Additionally, pH and organic matter were significant, which is likely caused by their strong inverse relationship. As SOM content increases, pH decreases, because the decomposition of the organic matter results in organic acids. Thus, if the amount of organic matter entering a system increases, the greater the amount of organic matter is being generated. pH and moisture content were significant at the 0.05 level, which can likely be explained by their direct relationship. As moisture content decreases, pH does as well, because the water is not only reacting with the particles in the soil, but, in extreme cases, it also may wash away chemical components that would otherwise keep the soil in a more alkaline state (Zarate-Valdez et al., 2006). pH and organic matter also showed significant correlation with phosphorus content at the 0.05 level. As explained previously, pH and organic matter have a highly significant relationship, and phosphorus is most available when in the pH range of 6.0 to 7.0 (Jeschke, 2017). The types of organic matter added to the soil, specifically the mushroom compost fertilizer, also likely aided in phosphorus production and availability. Overall, the pH and SOM conditions have created an ideal environment for the nutrient, likely resulting in their statistically significant relationship.

Fungal & Bacterial Colonies

In addition to the physical and chemical properties of the soil, microbial health also plays a key role in determining overall soil health. The bacterial and fungal populations are presented and discussed in Tables 8 and 9, as well as Figure 11.

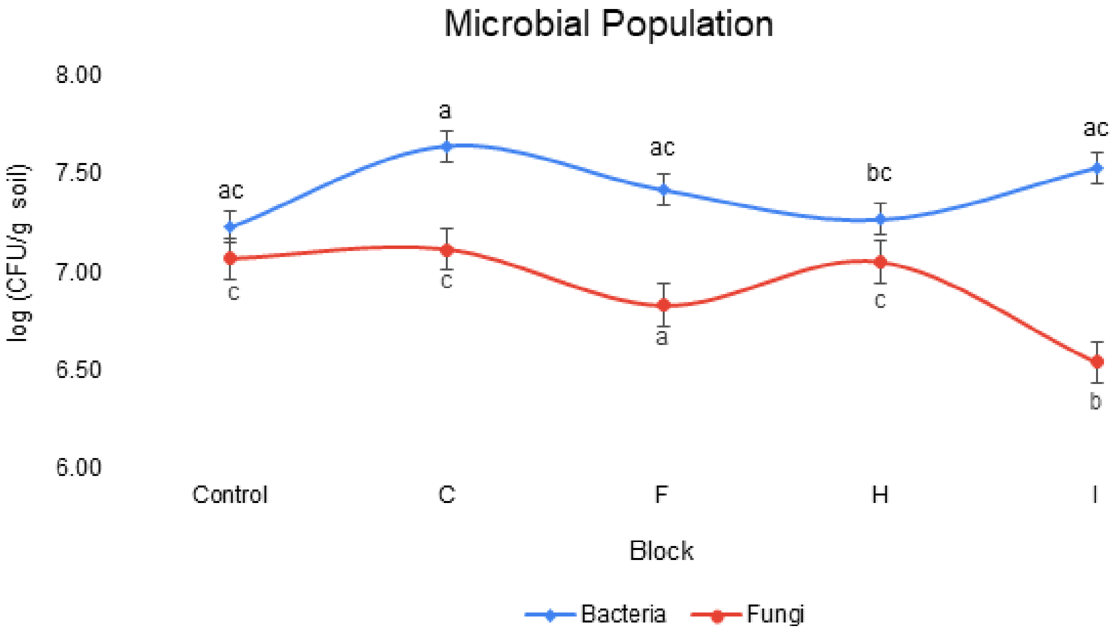

Figure 11. The average fungal and bacterial colonies for each block.

Although soil microorganisms have different functions, their comparison is important when discussing overall soil health. As indicated by Figure 11, there was a significant difference in bacterial colony population between blocks C and H, which is demonstrated by their lack of a common letter in the statistical analysis. However, both blocks displayed similarity to each of the other sampled areas. Because bacterial colonies prefer a more neutral environment, it is uncharacteristic for block C to have such a high bacterial count, as it had the lowest pH out of all of the sampled areas. It may have been more suitable to bacterial colonies in other ways, such as its low bulk density and healthy level of nitrogen. Block H showcased the lowest bacterial population out of all of the sampled areas despite its suitable chemical environment. However, it had the highest bulk density and lowest porosity, meaning that there is not as much aeration and water flow between soil particles, which may cause issues for soil bacteria to receive the resources they need to grow and reproduce.

As shown in Figure 11, the fungal colonies for blocks F and I were significantly different in comparison to the other three sampled areas, as well as to each other. Fungal colonies tend to prefer acidic environments, meaning that it is important to include pH as a factor in the explanation. For example, block C showcased the highest fungal population, as well as the lowest pH out of all of the sampled areas. Blocks F and I both had pH levels over the neutral 7.0, which is less favorable for fungal growth and reproduction. In blocks where the fungal colonies were especially low, it can be assumed that the soil conditions were more favorable to support bacterial growth. Additionally, both block F and I had lower soil moisture levels in comparison to blocks with high fungal populations, such as blocks C and H. The reasoning behind the difference in fungal populations can likely be attributed to a mixture of both physical and chemical parameters.

Table 8. The *p* values for the effect of different blocks on soil microbial population.

Sources of Variation	Bacteria	Fungi
Block	0.01*	<0.001*

* = Significant at $p < 0.05$; Values not included were not significant.

As shown in Table 8, the data for both the bacterial and fungal colonies showed statistical significance, meaning that there was significant influence on the bacterial and fungal colonies due to the different blocks. Although the blocks are located in similar areas and receive similar agricultural treatments, there are still differences in their overall soil conditions. This creates a difference between how suitable the environments are for microbial growth and activity.

Table 9. Pearson's multiple correlation coefficient values for the relationship between soil physical and chemical properties with microbial population.

	Moisture	Bacteria	Fungi
Moisture	1	-	0.57*

*=Correlation is significant at the 0.05 level; Values not included were not significantly correlated.

Out of all of the physical and chemical parameters studied, only moisture significantly influenced fungal colonies in the blocks, as shown in Table 9. This is likely due to the presence of favorable growth conditions for fungi. The optimal growth conditions for several fungal species consist of a temperature between 25℃ to 30℃, as well as an environment with a pH ranging from 5 to 6 (Ali et al., 2017).

Yield

Although plant yield does not wholly determine whether a soil is at peak health, it is a reliable indicator of weaknesses in a given type of soil property.

Table 10. Crop type and yield of each block.

Block	Crop	Yield (lbs.)
C	Kale	44.00
	Rainbow Chard	35.20
F	Napa Cabbage	619.15
	Cabbage	53.55
	Lettuce	162.55
	Watermelon Radish	38.25
H	Skinny Eggplant	112.80
I	Bell Pepper	481.90
	Shishito Pepper	68.00

Table 10 showcases the yields for the specific crops in each block. Since the control is not cultivated, it is obviously not included. Additionally, the standard deviation would not provide any sort of contribution to the analysis, so it was not included. The overall yield per block varies based on the soil parameters as well as the crop types and the growing and harvesting seasons, which offers explanation as to why there is so much variation in crop weight per block.

Conclusion

Because of the inherent heterogeneity of soil, it is important to monitor any changes as a result of agricultural practices. Soil characteristics can vary greatly, and overall soil quality is determined by myriad factors and parameters. The data produced by this study showed variation in some parameters between the control and the blocks, as well as between the blocks themselves. Because this study serves as a baseline study at *Grow It Green*, this information can be useful for monitoring changes in soil quality, and modifying management practices accordingly. As there is no previous data to compare to the results of this study, most of the soil parameters indicate that GIG is within range of optimal productivity levels. The farm has been practicing for 15 years, so it will offer a wealth of information to see how it will change soil quality over time. Regularly surveying and monitoring land allows farmers and researchers alike to have a better understanding of soil conditions, which will then encourage the selection of appropriate management practices for desired crop production.

This study has the possibility to be furthered in a variety of ways, especially through longer sampling and observation periods. Because this study is the first of its kind at *Grow It Green*, there is potential for a tremendous growth of information. Through a routine analysis of the soil, observations can be made about how the different parameters change over time. Not only will this help the farmers understand its soil's functions and needs, but it will also allow them to easily adjust their practices in order to maintain yield without sacrificing soil health. This study used land that was not farmed as a form of control, but it would also be helpful to conduct research on land that has been conventionally farmed in order to quantify the differences between them.

On a larger scale, the furthering of this research at GIG will also allow for observation regarding the long-term success of urban farming. The ultimate goal is to continue to supply food for an ever-growing human population while minimizing environmental harm. Sustainable urban organic farming focuses on environmental protection in order to find the balance between human needs and environmental sustainability. Information from this study is not only helpful for farming on a local scale, but it is transferable to areas with similar agro climatic conditions on regional and global scales. The usage of sustainable practices such as cover cropping and companion planting are transferable to a wide array of climatic circumstances. Although there may be variation in the outcome, this information can be useful for understanding the variability that comes with cultivating different crops, and the potential success for different management practices. Because existing urban farms and community gardens have already shown so much support to their respective communities, the popularization of this agricultural style has great potential to reduce food insecurity and increase aspects such as social engagement and nutrition education.

References

Abass Ahanger, Mohammed, Moradtalab, Narges, Abd Allah, Elsayed, Ahmad, Parvaiz. (2016). Plant growth under drought stress: Significance of Mineral Nutrients. *Water Stress and Crop Plants: A Sustainable Approach,* 2.

Ali, Sadiq, Fradi, Ahmed, Al-Aaraji, Alaa. (2017). Effects of some physical factors on growth of five fungal species. *European Academic Research,* 5(2).

Azarbad, Hamed. (2022). Conventional vs. Organic Agriculture-Which One Promotes Better Yields and Microbial Resilience in Rapidly Changing Climates? *Frontiers in Microbiology,* 13.

Barthel, Stephan, Isendahl, Christian, Vis, Benjamin, Drescher, Axel, Evans, Daniel, Van Timmeren, Arjan. (2019). Global urbanization and food production in direct competition for land: Leverage places to mitigate impacts on SDG2 and on the Earth System. *The Anthropocene Review,* 6(1-2):71-97.

Bell, Terrence, Borrelli, Kristy, Isabell, Sarah, Fleischmann, Suzanne, Kaminsky, Laura, Cloutier, Mara. (2021). Understanding and Managing Soil Microbes. Pennsylvania State University.

Bey R. Microbiology Laboratory Manual (2001). Wadsworth Group, Thomson Learning Inc. USA.

Bhunia, Shantanu, Bhowmik, Ankita, Mallick, Rambilash, Mukherjee, Joydeep. (2021). Agronomic Efficiency of Animal-Derived Organic Fertilizers and Their Effects on Biology and Fertility of Soil: A Review. *Agronomy,* 11, 823.

Buerkert, Andreas, Joergenson, Reiner, Ludwig, Bernard, Schlect, Eva. (2012). Nutrient and Carbon Fluxes in Terrestrial Agro-Ecosystems. *Marschner's Mineral Nutrition of Higher Plants.*

Costello, Laurence. (2003). Abiotic Disorders of Landscape Plants. University of California.

Creamer, R.E., Barrel, J.M., Bongiorno, G., Zwetsloot, M.J. (2022). The life of soils: Integrating the who and how of multifunctionality.

Datta, Sumon, Taghvaeian, Saleh, Stivers, Jacob. (2017). Understanding Soil Water Content and Thresholds for Irrigation Management. *Oklahoma State University.*

Dawson, Lorna Anne. (2023). Soil science in the criminal justice system. *Encyclopedia of Soils in the Environment*, 3:521-531.

Diao, Wanying, Liu, Gang, Zhang, Huimin, Hu, Kelin, Jin, Xiuliang. (2021). Influences of Soil Bulk Density and Texture on Estimation of Surface Soil Moisture Using Special Feature Parameters and an Artificial Neural Network Algorithm. *Agriculture,* 11(710).

Edward J. Ciolkosz, William J. Waltman, Thomas W. Simpson, Robert R. Dobos. (1989). Distribution and genesis of soils of the northeastern United States. *Geomorphology*, 2(1–3): 285-302.

Fenton, Megan, Albers, Carl, Ketterings, Quirine. (2008). Soil Organic Matter. *Cornell University Agronomy.*

Frąc, Magdalena, Hannula, Silja, Belka, Marta, Jędryczka, Małgorzata. (2018). Fungal Biodiversity and Their Role in Soil Health. *Frontiers in Microbiology,* 9:707.

Harada, Yoshiki, Whitlow, Thomas. (2020). Urban Rooftop Agriculture: Challenges to Science and Practice. *Frontiers,* 4.

Hatfield, Jerry, Sauer, Thomas, Cruse, Richard. (2017). Soil: The Forgotten Piece of the Water, Food, Energy Nexus. *Advances in Agronomy,* 143:1-46.

Hemkemeyer, Michael, Schwalb, Sanja, Heinze, Stefanie, Joergensen, Rainer. (2021). Functions of elements in soil microorganisms. *Microbiological Research,* 252.

Herawati, A., Mujiyo, Syamsiyah, J, Baldan, S.K., Arifin, I. (2020). Application of soil amendments as a strategy for water holding capacity in sandy soils. *IOP Earth and Environmental Science,* 724.

Hill, Holly. (2008). Food Miles: Background and Marketing. *ATTRA.*

Hochmuth, G.J., Hanlon, E. (2022). Plant Tissue Analysis and Interpretation for Vegetable Crops in Florida. University of Florida.

Holmes, Darnell. (2022). Lenni Lenape and Modern Practices: Forming a Collective Model to Future Agriculture. *Harvard University.*

Jain, Ankur. (2018). Analysis of Growth and Instability in Area, Production, Yield and Price of Rice in India. *Social Change and Development,* 15(2).

Jat, Mangi, Singh, Bijay, Stirling, Clare, Jat, Hanuman, Tetarwal, Jagdish, Jat, Raj, Singh, Rajbir, Lopez-Ridaura, Santiago, Shirsath, Paresh. (2018). Soil Processes and Wheat Cropping Under Emerging Climate Change Scenarios in South Asia. *Advances in Agronomy,* 148:111-171.

Jeschke, Mark. (2017). Phosphorus Behavior in Soil. *DuPont Pioneer Agronomy Sciences.*

John, Daisy, Babu, Giridhara. (2021). Lessons From the Aftermath of the Green Revolution on Food System and Health. *Frontiers in Sustainable Food Systems,* 5:644559.

Karunarathne, Ayanthi, Gunnell, David, Konradsen, Flemming, Eddleston, Michael. (2019). How many premature death of pesticide suicide have occurred since the agricultural Green Revolution? *Clinical Toxicology,* 58(4):227-232.

Kim, Nakian, Zabaloy, María, Guan, Kaiyu, Villamil, María. (2020). Do cover crops benefit soil microbiome? A meta-analysis of current research. *Soil Biology and Biochemistry,* 142.

Langemeyer, Johannes, Madrid-Lopez, Cristina, Mendoza Beltran, Angelica, Villalba Mendez, Gara. (2021). Urban agriculture– A necessary pathway towards urban resilience and global sustainability? *Landscape and Urban Planning.*

Lathrop, R.G. and Hasse, J. (2016). Changing Landscapes in the Garden State: Land Use Change in NJ 1986 through 2015. Rutgers University.

Lindström, Kristina, Murwira, Mazvita, Willems, Anne, Altier, Nora. (2010). The biodiversity of beneficial microbe-host mutualism: the case of rhizobia. *Research in Microbiology,* 161:453-463.

Marx, E.S., Hart, J., Stevens, R.G. (1999). Soil Test Interpretation Guide. *Oregon State University.*

Mikhailova, Elena, Lin, Lili, Hao, Zhenbang, Zurqani, Hamdi. (2022). Conflicts of Interest and Emissions from Land Conservations: State of New Jersey as a Case Study. *Geographies,* 2(4):669-690.

Moore, Julia, Mascarenhas, Alekhya, Bain, Julie, Straus, Sharon. (2017). Developing a comprehensive definition of sustainability. *Implementation Science,* 12:110.

Msimbira, Levini, Smith, Donald. (2020). The Role of Plant Growth Promoting Microbes in Enhancing Plant Tolerance to Acidity and Alkalinity Stresses. *Frontiers in Sustainable Food Systems,* 4:106.

Muhammed, Ihsan, Wang, Jun, Sainju, Upendra, Zhao, Fazhu. (2020). Cover cropping enhances soil microbial biomass and affects microbial community structure: A meta-analysis. *Geoderma,* 381.

Munna, Nayem Husan. (2019). 12 Soil Orders in Soil Taxonomy with Their Major Characteristics. *Earth Review.*

Naorem, Anandkumar, Maverick, Jaison, Singh, Puja, Kumar Udayana, Shiva. (2021). Microbial community structure in organic farming and their management. *Advances in Organic Farming,* 47-58.

Nardy Noerman, Najib et al. (2023). IOP Conf. Ser.: Earth Environ. Sci. 1180 012043.

Padje, Anouk, Werner, Gijsbert, Kiers, Toby. (2020). Mycorrhizal fungi control phosphorus value in trade symbiosis with host roots when exposed to abrupt 'crashes' and 'booms' of resource availability. *New Phytologist*, 229: 2933-2944.

Parmar, Dhruvika. (2023). A Review: Child Malnutrition and Poverty. *International Journal of Research and Analytical Reviews,* 10(2).

Potdar, Revati, Verma, Alok, Kulkarni, A. (2021). Determination of soil nutrients (NPK) using optical methods : a mini review. *Journal of Plant Nutrition.*

Royte, Elizabeth. (2015). Urban Farming is Booming, But What Does It Really Yield? *Food and Environment Reporting Network.*

Semeraro, Teodoro, Scarano, Aurelia, Buccolieri, Riccardo, Santino, Angelo, Aarrevaara, Eeva. (2021). Planning of Urban Green Spaces: An Ecological Perspective on Human Benefits. *Land,* 10, 105.

Tahat, Monther, Alananbeh, Kholoud, Othman, Yahia, Leskovar, Daniel. (2020). Soil Health and Sustainable Agriculture. *Sustainability,* 12, 48-59.

Teague, Richard, Kreuter, Urs. (2020). Managing Grazing to Restore Soil Health, Ecosystem Function, and Ecosystem Services. *Frontiers in Sustainable Food System,* 4:534187.

USDA State Agriculture Overview. (2023). New Jersey.

Umesha, Sharanaiah, Manukumar, Honnayakanahalli, Chandrasekhar, Bhadvelu. (2018). Sustainable Agriculture and Food Security. *Biotechnology for Sustainable Agriculture,* 67-92.

Yang, Tony, Siddique, Kadambot, Liu, Kui. (2020). Cropping systems in agriculture and their impact on soil health- A review. *Global Ecology and Conservation,* 23.

Zarate-Valdez, Jose, Zasoski, Robert, Läuchili, André. (2006). Short-term effects of moisture content on soil solution pH and soil Eh. *Soil Science,* 171, 423-431.

Zepeda, Lydia. (2018). Hiding hunger: food insecurity in middle America. *Agriculture and Human Values,* 35:243-254.