An Assessment of Soil Health and Productivity in Urban Gardens

Thesis

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By

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Abstract

Expanding production is one strategy for increasing access to key foodstuffs in distressed neighborhoods. However, concerns about soil quality driven by various anthropogenic disturbances hamper urban agriculture. This study investigated urban soil health via nematode food web analysis and crop productivity via tomato fruit yield in urban gardens in Cleveland, Ohio, USA over two years. Two hypotheses were tested: 1) the market gardens would have higher soil health and crop productivity than the community gardens since market gardens are driven by profit motives to produce quality crops, and 2) the gardens using raised beds would have improved soil health and crop productivity over the gardens using flat beds in garden preparation. Results for the first hypothesis comparing garden types indicate that the market gardens had significantly more soil organic matter (SOM) in 2011 (10.1±0.4 vs. 6.03±0.5) and 2012 (8.8±0.5 vs. 6.6±1.1); the market gardens in 2011 also had greater \( \text{NH}_4^+ \) (3.3±0.2 vs. 2.2±0.3), \( \text{NO}_3^- \) (37.8±3.3 vs. 20.6±2.8), dissolved organic nitrogen (DON) (24.8±2.2 vs. 15.6±1.7) and microbial biomass nitrogen (MBN) (100.7±7.5 vs. 69.3±6.4). In 2012 only the MBN (153.4±11.1 vs. 68.8±9.5) was significantly greater in market gardens compared to community gardens. In 2011, the nematode food web analysis showed a greater numbers of total nematodes (75.4±4.9 vs. 47.6±5.0/10g soil), bacterivores (47.6±3.9 vs. 28.3±3.4), plant parasitic nematodes (16.8±1.6 vs. 11.3±1.7), and omnivores (4.0±0.6 vs. 1.7±0.3) in market gardens than the community gardens. In 2012, market gardens again had
significantly more total nematodes (64.3±16.6 vs. 19.3±4.0), nematode genera (5.9±0.4 vs. 4.4±0.3), bacterivore (24.6±3.4 vs. 10.3±1.3) and plant parasitic nematode trophic groups (5.4±1.1 vs. 1.9±0.4). Despite the greater SOM, N pools, and soil community presence in market gardens, there was no significant difference in the total yield of tomatoes/m² produced in either year between the garden types. Results for the second hypothesis comparing production systems indicate that gardens with raised beds also had significantly more soil moisture content in both 2011 (23.7±0.9 vs. 20.4±1.4) and 2012 (22.5±1.2 vs. 16.2±0.7) as well as SOM in both 2011 (10.0±0.4 vs. 6.2±0.6) and 2012 (3.0±0.1 vs. 2.3±0.1). N pool comparison showed gardens with flat beds having higher NH₄⁺ (3.4±0.2 vs. 2.5±0.2) in 2011, but gardens with raised beds having higher NH₄⁺ (19.8±3.0 vs. 12.5±1.4) and MBN (140.1±12.2 vs. 88.7±11.3) in 2012. However, in 2011, gardens with raised beds had greater numbers of total nematodes (192.8±30.6 vs. 66.9±14.1), bacterivores (46.0±3.8 vs. 30.7±4.0), plant parasitic nematodes (17.6±1.8 vs. 10.0±1.1), and omnivores (4.3±0.6 vs. 1.3±0.2) as well as a higher MI (1.9±0.1 vs. 1.6±0.0), combined MI (1.9±0.0 vs. 1.8±0.0) and SI (38.8±3.9 vs. 25.3±3.4) while gardens with flat beds had greater numbers of fungal feeders (8.1±1.7 vs. 5.2±0.8) and a higher EI (80.6±1.7 vs. 72.6±2.5). In 2012, only the gardens with raised beds had greater numbers of total nematodes (64.1±16.7 vs. 19.6±2.9) and bacterivores (23.6±3.4 vs. 11.7±1.8); the gardens with flat beds had a higher CI (23.6±4.9 vs. 9.5±2.4). There was no significant difference in the total yield of tomatoes/m² produced in either year between the production systems. In 2012, Celebrity tomatoes were planted in all gardens and their growth was monitored in addition to the fruit yield. The community garden plants had a
significantly greater plant surface area (1391.1±87.7 vs. 1170.0±63.0), leaf surface area (24.6±1.6 vs. 20.9±1.2) and leaf dry weight ratio (23.2±0.4 vs. 21.9±1.4) than the market garden plants while the gardens with raised beds had greater plant height (31.3±1.3 vs. 26.6±1.7), plant surface area (1427.5±65.6 vs. 972.2±92.6) and leaf surface area (23.9±0.9 vs. 20.0±1.0) than gardens with flat beds, which had greater leaf dry weight ratios (23.7±0.4 vs. 21.8±0.3) than the gardens with raised beds. While some of the variation in results from 2011 to 2012 was likely due to drastic differences in the weather between these years, there was still a trend for market gardens and gardens with raised beds to have more ideal soil conditions for growing vegetable crops in urban gardening systems. It is likely that none of the gardens were nutrient limited and therefore had similar tomato fruit yields, between 1.47 and 15.72 kg/m², which is comparable to national average yields in agroecosystems.
Dedication

To all the lights in the harbor, who keep me sailing safely along on my journey.
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Chapter 1: Introduction

1.1 Historical Reasons for Urban Gardening

Gardening has long been used by Americans all over the country to provide food, social services and recreational opportunities. As far back as 1910, gardening was recorded as a method for combating increasing food prices and shortages, as well as general economic hardship (Schupp & Sharp, 2011; Tucker, 1993). Recognition of the educational benefits of gardening started in the 1890s when the first American school gardens were developed. These gardens created green spaces in highly industrial urban centers where children were expected to experience nature and discover the benefits of hard work while they were socialized into upstanding American citizens (Trelstad, 1997). School gardening programs eventually expanded to address national food security issues during the World Wars when the number of War and Victory Gardens increased substantially. As a result of government promotion, 1.5 million students were producing food in over 60,000 acres, with another 20 million families managing their own home gardens (Miller, 2003; Trelstad, 1997; United States Department of Agriculture, 2011). And yet, this national movement quickly disappeared after World War II. While gardening remained a leisure activity during the post-war period, it is possible that the technological advances in farming that allowed fewer farmers to provide food for urban residents limited interest in gardening (Becker, 1984; Tice, 1984).
And yet, gardening still persists. Many of the old school gardens have been converted to community gardens where area residents can grow food for personal consumption. New community gardens are also being built in cities across the U.S. where vacant lands are taken over by neighborhood civic associations for repurposing of the land (Accordino & Johnson, 2000). In recent years, personal food production through home and community gardening was expected to reach 43 million households of the 112 million total US households in 2009 (Census Bureau, 2010). This would be a 19% increase over those who grew their own food in 2008 (Butterfield, 2009). Additionally, market gardens, gardening enterprises that sell surplus or all grown produce through farmer’s markets and on-site stands, have begun appearing in urban centers (Airriess & Clawson, 1994). These for-profit enterprises have become more prevalent in the past ten years, working to meet the growing demands for local food, provision of social services and creation of green areas.

1.2 Contemporary Reasons for Urban Gardenings

Food insecurity is a nationwide concern because 6% of all US households do not always have the food they want or need, due to lack of money or lack of available food (ver Ploeg et al., 2009). The concept of food deserts, an area where fast food restaurants are 4.5 times closer than a grocery store according to Masi (2008), has received national attention at a time when 5.7 million households live more than half a mile from the nearest grocery store, with no vehicle to help transport them or their groceries (ver Ploeg et al., 2009). While these households are threatened with a lack of nutrition, many Americans are also affected by malnutrition and overweight issues: 34.2% of US adults
are considered overweight, with another 39.5% qualifying as obese or extremely obese (Ogden & Carroll, 2010). These two demographics are not as separate as one might think, as Americans who do not shop at supermarkets are more likely to purchase highly processed and low nutritional foods at convenient stores (ver Ploeg et al., 2009).

Creating urban gardens increases access to healthy food by increasing access to areas where healthy food is grown either by those in need, or for purchase to those in need. A study on urban food production in Cleveland determined that, depending on how intensely vacant lots, residential lawn space and rooftops were adapted to food production, the city could grow between 22% to 100% of its produce needs (Grewal & Grewal, 2011). In addition to providing fresh produce for city residents, the conversion of these areas to support food production, and the food production itself, would create a variety of new employment opportunities.

Even if such a bold plan were not fully implemented, urban gardens have been used as a way to address economic concerns after the 2008 recession. The recession resulted in a plethora of foreclosed houses – especially in post-industrial Midwestern states such as Ohio and Michigan (Calomiris et al., 2008). In addition to creating swaths of vacant and unused land in downtown areas, cities are losing population as people move to areas where job opportunities are available. As it is, there are 46.2 million people, or 15.1% of the entire US population, living in poverty conditions – almost half of these people have an income of less than half of the poverty threshold (DeNavas-Walt et al., 2011). Developing urban agriculture in these economically depressed cities could provide employment opportunities in whole food production, value-added food product
creation, marketing, and small business management, to name a few job sectors. An additional benefit is that repurposing vacant land by developing it into urban gardens puts people and activity in areas that might otherwise become neglected and crime ridden (Krumholz & Brown, 2005; Schukoske, 1999).

1.3 Challenges to Overcome

It is not always easy to turn a vacant lot into an urban garden. Urban soil is defined as “material that has been manipulated, disturbed or transported by man’s activities in the urban environment” (Craul, 1985) and is often believed to be unsuitable for growing plants in any capacity. The disturbance and mixing that is part of the transportation of soil in urban areas can lead to a uniform distribution of nutrients throughout the soil layers rather than having them readily available near the root zone of plants (De Kimpe & Morel, 2000). Disturbance can lead to beneficial microorganisms in the soil being moved away from the microenvironments where they flourish and provide their ecological services (Craul, 1985). But rather than decreasing the presence of soil microorganisms, an unexpected result of this disturbance is actually a high presence of diverse soil microorganisms that would not otherwise be observable as they fill the many environmental niches opened by the disruption of soil layers and aggregates (Pouyat et al., 2010).

Another reason for the perception of nutrient limitation may stem from how plant litter is removed for visual aesthetics, resulting in oxidation of exposed topsoil and nutrient deficiency (Scharenbroch & Lloyd, 2004). And yet, it has also been demonstrated that N can be retained in urban systems about as well as in natural systems
(Pickett et al., 2008). If nutrient loss is cited as a result of soil disturbance, then as time passes since disturbance, the nutrient capacity increases, resulting in urban areas having recovered from the disturbance and having a greater nutrient availability than newly disturbed urban areas (Park et al., 2010; Scharenbroch et al., 2005). Despite arguments on both sides regarding nutrient availability, urban soils play an important role in carbon cycling by storing soil organic carbon, and partially mitigating the rising atmospheric CO₂ levels cited as a part of global climate change (Lorenz & Lal, 2009; Pickett et al., 2008). However, this mitigation does not occur at a constant rate, and depends heavily on the parent material and land use of the urban soil. In fact, the wide variation in soil characteristics that facilitate carbon sequestration actually demonstrates a wide variation in nutrient (both macro- and micronutrients) availability. This variation means that some urban soils nutrient content is on the high end (Cheng et al., 2008), so that it meets, and even exceeds, recommended nutrient availability for horticultural purposes (Pickett et al., 2008).

Higher pedestrian traffic in urban areas can lead to greater soil compaction, which can impact the development of plant roots as well as decrease the rate of N fixation by up to 20% when compared to land covered by clover and other N fixing bacteria symbiotic plants (Breland & Hansen, 1996; Jim, 1998; Oliveira & Pampulha, 2006). When considering garden areas where such foot traffic can be reduced or prevented, tillage, a common agricultural practice, can also lead to soil compaction. Urban areas also utilize a lot of concrete for sidewalks and building material. Concrete and other paved surfaces absorb the sunlight that would otherwise be used or deflected by plants, leading to heat
islands within and across cities (Byrne, 2007). Sometimes, an entire city itself can become a heat island and affect local airflow and weather patterns which can impact city gardens by reducing rainfall and increasing ambient temperatures (Dixon & Mote, 2010; Wilby, 2003).

Furthermore, urban soil legacies, such as previous land usage, can impact an area’s suitability for being developed into a food production area. Urban soil legacies are contaminants left in soil from previous industrial, agricultural, or residential land use. Chemical contaminants such as pesticides and hydrocarbons can be degraded so they are no longer toxic or present in the soil. One method of remediation is achieved by adding organic matter as an energy source to stimulate microbial degradation of these pollutants (Papa et al., 2010). Without this addition, hydrocarbon contamination can also be an energy source for gram-negative bacteria, which can raise soil pH and improve the soil environment (Beyer et al., 1995; Kaplan & Kitts, 2004). However, metal contamination cannot be degraded and will remain a hazard in urban soils. Elevated levels of metals can negatively impact microorganisms and nematodes, and N fixing bacteria are particularly sensitive to the presence of metals (Oliveira & Pampulha, 2006). Microbial biomass and soil food web degradation may be more closely associated with lead content increases in urban soils rather than to the reduction of humus and organic matter in soil (Beyer et al., 1995; Yang et al., 2006).

1.4 Overcoming Challenges to Create Safe, Productive Urban Gardens

Despite these concerns regarding soil properties such as nutrient availability and presence of contamination, land management has been shown to have the greatest impact
on soil health and a soil’s ability to support plant growth. Soil health, especially when used with respect to gardening and agriculture, includes concerns of food safety, human and animal health when interacting with the land, and the quality of surrounding water (Papendick, 1992; Romig et al., 1995). Measuring it relies on observing ecological and biological characteristics of the soil such as the presence of various groups of organisms and the health of crops, but may also include non-biological characteristics such as presence of organic matter and lack of erosion (Romig et al., 1995; van Bruggen & Semenov, 2000). Alternately, soil quality tends to consider only the chemical characteristics that lead to high crop productivity alone (Papendick, 1992; Romig et al., 1995).

Urban soils in older cities tend to have an appropriate level of soil health that can benefit agricultural projects. Older cities have had a longer period of time for soils to recover from massive disturbance events associated with initial urban development, allowing chemical and biological properties to reestablish in ranges suitable for plant growth (Knight et al., In Press.; Park et al., 2010). The soil food webs in older city vacant lots are similar to soil food webs in newly established gardens in younger cities (Grewal et al., 2011), suggesting that these vacant lots have a similar initial soil health for supporting the production of vegetables, although the practice of adding nutrient amendments to maintain the soil health during vegetable production is recommended. In addition to providing nutrients to growing plants, these amendments can also shape the soil community population into one that thrives in a garden environment (Cheng et al., 2008; Park et al., 2010).
The link between soil health and sustainable practices appears to be intuitive. Papendick (1992) state that sustainable practices are ones that maintain a healthy, resilient, soil capable of recovering from natural or farming disturbances. Other definitions of sustainability in agriculture include maintaining soil fertility through recycling waste materials, using biological cycles and controls to prevent pest, disease and weed problems, as well as providing adequate goods and profit for human needs today and in the future (Bromilow RH, 2004; de Orellana & Pilatti, 1999; United States Congress, 1990). Even within an urban landscape, such sustainable practices are possible to implement when creating a healthy urban soil.

However, in urban agriculture, donation of food to charity, improvement of personal diets with fresh vegetables, and development of social ties are the major reasons for gardening (Blaine et al., 2010; Patel, 1996). Environmental issues, while sometimes present, are not at the forefront of motivations for gardening. Adoption of sustainable practices is not guaranteed by urban gardeners because the presence of organisms and the vibrancy of crops are not necessarily highly valued. Furthermore, the promise of additional environmental benefits will not entice those who do not already garden to begin doing so. Understanding how to entice non-gardening citizens to consider, and participate in, sustainable urban gardening is as important as understanding how to encourage sustainable urban gardening to those who already garden via the more traditional methods.

1.5 Determining Productivity in Urban Gardens
Secondary reasons for promoting urban gardening, such as combatting urban blight, increasing physical activity and social connections of people who garden, and reconnecting urban residents of all ages with nature and natural processes (Blaine et al., 2010; Patel, 1996; Schukoske, 1999; Trelstad, 1997; Tucker, 1993), have been well documented and studied, but actual food production in urban gardens has been little investigated. It is easier to take a census and estimate that over 60,000 acres of land were gardened during the world wars (Miller, 2003; Trelstad, 1997) and 43 million households were involved in gardening in 2009 (Census Bureau, 2010) than it is to track and study the amount of produce grown in these gardens. The field of sociology has an interest in tracking the activities that bind people together, so sociologists have used these kinds of surveys to study the mechanisms of how and why social capital is built in communities as a result of involvement in urban agriculture programs. Record keeping of food production is more directly related to an interest in tracking economics and food supply. As the national government keeps records of large industrial food production as a means of protecting against food shortages, it would be in the best interest of city governments to track urban food production as a way to anticipate local food trends and needs. Much, if not all, of the technological advances made in the past century have been for the benefit of large agricultural endeavors in rural areas, leaving urban gardeners to continue to rely on labor and quality of planting materials influencing their food production (Becker, 1984; Tice, 1984; Umoh, 2006). Whatever practices are benefitting urban food production must relate to the soil and soil amendments that the urban gardeners work with.
Maintaining the soil and soil health is a concern for all agricultural systems – not just rural or urban ones. Soil erosion and nutrient deficiency are being combatted in agricultural fields all across the world (Scharenbroch & Lloyd, 2004). When dealing with soil health in agricultural systems, the inclusion of soil organic matter (SOM) is often considered important because it is noted for improving soil aeration, tilth, and moisture penetration and retention (Campbell, 1978). SOM is also made up of approximately 5% organic nitrogen (N), which becomes mineralized by the soil biological community into \( \text{NH}_4^+ \) and \( \text{NO}_3^- \), the two inorganic N forms taken up by plants (Alon & Steinberger, 1999). However, abundant SOM does not guarantee that N will be present in sufficient amounts or at the right time for optimal plant development.

This decomposition of SOM and provision of N, as well as regulation of pest species, are some of the many “ecosystem services” to be gained by managing the soil community rather than relying on inorganic chemicals (Ferris et al., 2001). “Ecosystem services” is a term used to describe the benefits humans gain from the environment, its organisms, and their interactions. Many times, these services are used to advocate for leaving an ecosystem undisturbed or for keeping it as close to a natural state as possible. One example of using ecosystem services to benefit humans would be the maintenance of the soil community in minimum disturbance for agricultural endeavors. However, promoting these ecosystem services requires understanding how agricultural land management affects soil biota (Ou et al., 2005).

While the soil community provides ecosystem services that can benefit plants, sometimes it is also in direct competition with these plants for mineralized N (Cookson et
al., 2007). Even if there is a high rate of mineralization, this rate can be the result of either an active or a large microbial community. Depending on the species composition, a microbial community with a small mass but fast metabolism can achieve a similar rate of mineralization as a large but low metabolism microbial community. Since N is used for proteins and other cellular structures, rather than respiration and energy production, a larger microbial community can have greater N demands to support the greater mass of microbial cells than a smaller massed but highly active microbial community. The rate of mineralization can also depend on the solubility of the SOM (Andersson et al., 2000). It has been suggested that the C:N ratio could influence the rate of N mineralization such that when an ecosystem becomes C limited, rather than N limited, the SOM will be decomposed for the organic carbon, and release mineralized N as a byproduct of this process (Bardgett, 2005; Schimel & Bennett, 2004).

These challenges in predicting the rate and timing of N mineralization make it difficult to manage agricultural systems exclusively with N sources from organic matter (El-Haris et al., 1983). However, direct additions of inorganic fertilizer do not eliminate N availability concerns. Alon and Steinberger (1999) noted that NO$_3^-$ was more likely to be found in soil for plant uptake since NH$_4^+$ is easily converted to NH$_3$, a gaseous form that volatilizes from soil, but that NO$_3^-$ was easily washed away from soils by rain and other heavy watering events. These kinds of excess N losses cost farms by removing the N added via expensive fertilizers that should have led to plant development.

Relying on the soil community to manage N availability is believed to retain N in the soil through immobilization in soil organisms, which turn over and release N during
periods of intensive plant growth activity (Schmidt et al., 2007). This also allows for a closed loop of production-consumption in farming systems as animal manures and plant residues get applied to fields as nutrient sources rather than transported to landfills and treatment stations as waste materials.

Since it is difficult to monitor all of the organisms in the soil community, nematodes are often used as an indicator species for the rest of the soil food web. This is because nematodes occur at multiple trophic levels of the soil food web, are easily identifiable under a microscope, and the relationship between their oral morphology and feeding habits facilitates classification into various trophic level groups (Bongers & Bongers, 1998; Briar et al., 2007; Neher, 2001). Analysis of the abundance of the different nematode trophic groups provides clues into the condition of the entire soil food web. Nematodes exist on a gradient from “colonizers” to “persisters” (c-p). Colonizers are often overly abundant in highly disturbed soils where nematodes with high reproductive rates recover quickly from environmental stresses while persisters are more likely to be found in low stress and stable environments (Bongers, 1990).

Nematodes are given a value from 1 to 5 along this c-p gradient depending on how they respond to different environmental conditions. For example, c-p 2 nematodes are prolific in disturbed environmental conditions while c-p 1 nematodes are more likely to be found as a result of nutrient enrichment (Ferris et al., 2001). Each c-p guild is then weighted to account for frequency of presence in the soil, and used to determine the basal, enriched and structured conditions of the soil food web (Figure 1). Food web indices are then calculated to give insight into the level of disturbance, enrichment and
other conditions of the soil environment. These indices are how knowledge of nematode feeding preferences along with environmental stress tolerances leads to an understanding of the kind of soil environment these nematodes are surviving in, and what other kinds of soil organisms would also be found under those conditions.

Nematodes are also sensitive to soil chemical conditions, as well as the soil environment. They depend on soil moisture to provide water films for movement through soil pores and their cuticle is in direct contact with the soil solution, exposing them to soluble chemicals in the soil (Yeates & Bongers, 1999). How nematode populations respond to these conditions also makes them good indicators for soil conditions over time as opposed to the snapshot of information typically gained from chemical or nutrient analysis.

The relative abundance of different nematode trophic groups can indicate the types of regulatory forces affecting the entire soil food web. For example, if predacious nematodes are highly abundant, “top-down” trophic pressures would be in effect. This usually occurs when herbivorous trophic levels are not food limited and are controlled only through predatory pressures (Hairston et al., 1960; Hunter & Price, 1992). If such a nematode food web were to be found, it would indicate that environmental conditions support a large presence of bacteria, fungi and plant matter for the lower bactivorous, fungivorous and herbivorous nematodes, and there is a lack of soil disturbance that would kill the larger omnivorous and predatory nematodes. It is more likely that one would find a “bottom-up” food web where plants and the microbial community regulate the lower trophic levels of nematodes, which then influence the presence of omnivores and
predators (Hunter & Price, 1992; Scherber et al., 2010). Either way, understanding the nematode trophic groups in the soil and how they are affecting one another can explain the condition of the rest of the soil food web.

Timing ecosystem services between the soil community and plant ecosystem is a challenge to ensure that the appropriate conditions for plant growth are present at the ideal time for maximum growth. The soil community already works commensally with the plant ecosystem as members of the soil community that exist in the rhizosphere exchange nutrients and water for sugars excreted from plant roots. However, each crop interacts with its rhizosphere in a different way. How best to determine the benefit of management practices between different gardening models and management practices that can include any of the numerous vegetables available for small scale production? One way is to compare the yield of a common agricultural crop, such as the most popular commodity and home-grown crop of tomatoes.

Tomato popularity as a commodity crop is reflected in the approximately 7.98 kg of tomatoes per person being consumed annually in the United States in the late 1990s (Lucier et al., 2000). This consumption comes from any number of sources that involve fresh and/or processed tomatoes as a way to increase consumption of the vitamins A and C, as well as disease-reducing carotenoids (Gao et al., 2010). These sources include ketchup, tomato juice, and any of the numerous dishes, especially Italian and Mexican, enjoyed in America that incorporate tomatoes into sauces.

The suitability of tomatoes for home production comes from tomato plants’ ability to be grown in small spaces or in containers, and still produce 3 to 5 kg of fruit per
plant (Gao et al., 2010). For example, mid-sized tomatoes have been shown to have an optimal point of yield per plant combined with yield per area at around 45 centimeter spacing between plants (Amundson et al., 2012). This also benefits commodity production of tomatoes as they can be a high cash crop for space confined producers, especially when producers focus on special heritage varieties that can fetch higher market prices. Because of their range of growing conditions, tomatoes are one of the few crops commonly produced across both the majority of community and market gardens, making them an ideal crop for investigating management practices in urban gardens.

Community gardens are typically areas of land that are subdivided so that families or individuals can manage these plots to produce food for home consumption. These gardens are frequently supported by city governments or other groups that provide funding and support to the garden. In exchange for this support, community gardeners are prohibited from selling their produce. Market gardens, however, are areas of land that are worked as a whole by groups of people whose goal is to sell produce and gain a profit with which to continue running the garden. Although community garden management practices can vary as they are run as a personal food production source or as a hobby, market gardens are run on a for-profit model as they need to obtain a certain productivity level in order to sustain the business.

While community gardens have existed in Cleveland since the early 1900s, market gardens only started being developed in the past two decades. A combination of vacant land combined with an interest in local food promoted the development of market gardens within the city borders. Interest in using urban food production as a way to
revitalize abandoned urban areas became especially important after the 2008 economic recession that left 19.3% of Cleveland’s land vacant or abandoned (Exner, 2011). Since urban food production can both lessen food security issues while also providing employment opportunities, there is a vested interest in determining how successfully these gardens are filling these expectations.

Within community and market gardens there was one garden preparation practice that stood out in the gardens: the establishment of raised beds versus in-ground planting. Raised beds are created by building soil and amendments into discrete beds, raising the bed planting surface above ground level, where crops are planted. In addition to layering amendments through the root zone, building raised beds results in a separation between walkways and cultivated areas throughout the garden. Flat beds also receive amendments, but these are tilled in below, or top dressed on, the soil surface. Flat bed gardens are less likely to be managed in rows, and are more likely to encourage travel and activity throughout the entire garden as there are no clear borders between planting and travel areas.

Therefore, this study was undertaken to investigate the relationship between the profit-driven and personal benefit-driven management practices, and of raised bed and flat bed production systems.

The specific objectives of this study were to:

1) Compare the chemical, physical, and biological characteristics of the soil, and tomato growth and fruit yield between community and market gardens.
2) Compare the chemical, physical, and biological characteristics of the soil, and tomato growth and fruit yield between raised bed and flat bed production systems.
Chapter 2: Materials and Methods

2.1 Site Acquisition

Ten urban garden study sites were identified in Cleveland, Ohio in the summer of 2011. All of the gardens are classified as being established on urban soil, which is best defined as non-agricultural soil in city areas that has been transported, thoroughly mixed, or otherwise affected through anthropological processes (Bockheim, 1974). The urban garden sites averaged in size around 0.51 hectares, but ranged overall from 0.12 hectares to 2.02 hectares.

Four of these sites were community gardens run in conjunction with the Ohio State University Extension Summer Sprout program. The community gardens were established in connection with area schools in the early to mid-1900s, originally as part of a city wide school gardening program (Table 1). As the school gardening programs ended, the gardens were taken over by the community and continued as places where residents could manage their own plots within the larger garden to grow food for personal consumption.

The other 6 sites were market gardens run by one of three social organizations that worked with 1) refugees from Eurasia, 2) adults with developmental disabilities, or 3) inner city school-aged young adults. Most market gardens had been established in the past 10 years as part of the city plan to deal with vacant land (Table 1). Establishment
locations were dependent on the availability of vacant land of an appropriate size and free of contaminants. The market gardens tend to have a single management practice for the entire garden as they are managed by a single person, or group of persons working together, growing food to sell on-site or at a Farmer’s Market.

The main management practice difference between these gardens was the building of raised beds or the use of flat beds for planting vegetables. Raised beds were built in six of the gardens by either mixing soil amendments into the ground in a bed-shape or shaping the mixture into a mound of raised soil on an already established raised bed, at least 7.5 cm and up to 15.25 cm higher than the surrounding area. The flat beds in the other four gardens were also prepared with the addition of soil amendments, but without specifically shaping the soil into a separated raised mound. Some other management practices also differed between the gardens, but the differences were not as marked as those between the motivation of gardening and garden bed preparation. A few gardeners used straw as a weed barrier, all added either compost or manure, and some used drip irrigation while others relied on hand watering (Table 1).

2.2 Soil Physical and Chemical Characteristics

2.2.1 Soil Sampling

Each garden was mapped and partitioned into approximately 6 meter by 6 meter sections. Nine of these sections in each garden were randomly selected for soil sampling. Nine soil cores, 2 cm in diameter and up to 10 cm in depth, were taken from randomly selected areas within each section. These 9 soil cores were then composited together into a single soil sample for each section within the garden for further analysis.
Samples were placed in polyethylene bags to prevent moisture loss and were kept in a cooler during transportation to the laboratory and during processing. Samples were stored at 4° C before analysis to preserve soil chemical and biological properties (Barker et al., 1969). Samples were taken once during June of 2011, and once during June of 2012. Analysis was conducted as follows:

2.2.2 *Soil Moisture and Total Organic Matter*

Soil moisture and organic matter content was determined according to a modified particulate organic matter method (Cambardella et al., 2001; Doran et al., 2001) where soils were first dried at 100° C for 12 hours. Pre- and post-drying weights were compared via

\[
\text{Water Content} = \frac{\text{Fresh Soil Weight} - \text{Dry Soil Weight}}{\text{Fresh Soil Weight}}
\]

Soils were then further dried at 360° C for another 4 hours to incinerate the organic matter present in the soil samples, and the amount of soil organic matter present in the soils was calculated with the equation

\[
\text{Soil Organic Matter} = \frac{\text{Dry Soil Weight} - \text{Ashed Soil Weight}}{\text{Dry Soil Weight}}
\]

2.2.3 *Soil Texture*

Soil texture was determined according to a modified pipette and sieving technique to separate soil particles (Gee & Bauder, 1986; Mccartney et al., 1997). Samples were
shaken with 5 g/L Na(PO₃) to break soil aggregates so sand, silt, and clay could be separated for measurement. After shaking, samples were allowed to sit for 20 minutes to settle out the sand and silt fractions before 5 ml of supernatant were removed and dried at 100° C to determine the clay fraction. The remaining soil solution was then washed through stacked sieves of 2 mm and 0.053 mm mesh. Rocks and gravel caught in the 2 mm sieve were disposed of. Sand caught in the 0.053 mm sieve was collected and ashed at 360° C for 5 hours. The percentages of sand and clay were calculated, with silt being calculated as the remaining percentage.

2.2.3.1 Clay Content

Clay content was obtained by calculating the dry soil weight component of the fresh soil, then determining the clay content of the 5 ml of supernatant, before extrapolating the data for the whole fresh soil sample.

Calculated Dry Soil Weight = (Fresh Soil Weight)*(1-Water Content)

Clay content in grams for the 5 ml = (Vial + Supernatant after drying)-(Empty Vial)

Total Clay content in grams = (30 + Fresh Soil - Calculated Dry Soil)*Clay content in 5 ml/5 ml

Clay fraction = Total Clay content/Calculated Dry Soil Weight

2.2.3.2 Sand Content

Sand content was determined by weight after all non-sand material was either washed out of the sieve or ashed out by the oven. So, what remained in the glass vial at the end of the pipetting and sieving procedure was the total sand content.

Sand content = (Vial + Sand after heating at 360° C)-Vial
2.2.3.3 Silt Content

The silt fraction is the remaining portion out of 1. Thus, the calculated clay and sand fractions are subtracted, and the remainder is the silt.

\[
\text{Silt fraction} = 1 - \text{clay fraction} - \text{sand fraction}
\]

2.2.4 Soil Nitrogen (N)

2.2.4.1 Mineral N Extraction

Mineral N was extracted by adding 0.5 M K₂SO₄ solution to soil and shaking on an orbital shaker before being centrifuged on an IEC (International Equipment Company, Damon, at 115 Volts, 7 Amps, 60 HZ and ¾ horsepower) Model 2K Centrifuge at 3000 RPM. The supernatant was then gravimetrically filtered through a P2 Whatman filter to isolate the N solution. Supernatant was stored in a freezer until further analysis to prevent degradation of the samples or mold growth.

Samples were then digested by alkaline persulfate oxidation (Cabrera, 1993). The dissolved organic N (DON) samples were reacted with O₂ generated from the persulfate solution according to the equation

\[
\text{K}_2\text{S}_2\text{O}_8 + \text{H}_2\text{O} \rightarrow 2 \text{KHSO}_4 + \frac{1}{2} \text{O}_2
\]

at 15 psi and 120° C to break the organic nitrogen compounds into inorganic compounds of NO₃⁻ and NH₄⁺.

All NO₃⁻ samples (including the broken down DON samples) were then processed overnight with Devarda’s alloy, which is an alloy of 45% aluminum, 50% copper and 5%
zinc, and 0.1 M H₂SO₄. This results in a chemical reaction that reduces NO₃⁻ to NH₄⁺ through the equation

\[ 3 \text{NO}_3^- + 8 \text{Al} + 5 \text{OH}^- + 18 \text{H}_2\text{O} \rightarrow 3 \text{NH}_3 + 8 [\text{Al(OH)}_4^-] \]

All NH₄⁺ samples (including the reduced DON and NO₃⁻ samples) were then analyzed using a modification of the indophenol blue technique in microtiter plates (Sims et al., 1995) to determine the NH₄⁺ fraction. These final NH₄⁺ measurements for each sample were then subtracted from each subsequent nitrogen reduction step to determine how much nitrogen came from each of the N fractions. Thus, the NH₄⁺ value for each sample was subtracted from the converted NO₃⁻ sample to determine how much nitrogen was in the NO₃⁻ fraction. And NO₃⁻ value was subtracted from the converted DON samples to determine how much nitrogen was in the organic N fraction. Each final nitrogen fraction value was expressed in ppm.

2.2.4.2 Microbial Biomass N Extraction

Microbial biomass N (MBN) was determined using a modification of the chloroform fumigation method described by Brookes et al. (1985) assuming an extraction efficiency of 0.45 for MBN (Jenkinson, 1988). Soil samples were chloroform fumigated for 48 hours to break open microbial membranes, releasing the N compounds stored in their cellular tissues into the soil. These samples were then analyzed along with the mineral N samples according to the process described above. The MBN fraction was then isolated by subtracting the DON value from the final MBN value and was expressed as ppm.

2.3 Nematode Community Analysis
2.3.1 Nematode Extraction

Nematodes were extracted from the soil samples taken in 2011 and 2012 using the Baermann funnel technique (Flegg & Hooper, 1970). Each Baermann funnel had a wire mesh platform set into the top edge of the funnel and then gently filled with enough deionized water to reach just past the level of the wire mesh. A P2 Whatman filter paper was laid across the mesh. Soil was then placed on the filter paper, and the water level was adjusted so that the soil was moist without becoming dissociated or flooded. The soil was kept suspended in water to allow nematodes to migrate out and settle into the bottom of the funnel set-up. After 72 hours, the bottom 30 ml of suspension containing the nematodes were collected from the bottom of the funnel into a plastic tube. Nematodes in the plastic tube were allowed to settle overnight at 4°C before removing and discarding the supernatant without disturbing the settled nematodes. An equal volume of boiling water was then added to kill the nematodes by raising the liquid temperature instantly to about 50°C.

2.3.2 Nematode Identification for Soil Food Web Analysis

Nematodes were then viewed on a microscope for identification and counting. The first 100 nematodes viewed were identified to the genus level using morphological characteristics and published taxonomic keys (Goodey & Goodey, 1963; Mai, 1975). All subsequent nematodes were then counted, without being identified, for a total population count. Final counts included the number of nematodes identified in each genus, the total number of identified nematodes, the total number of counted nematodes, and the total
number of genera identified. These counts were not corrected for extraction efficiency, which is about 85% for the Baermann funnel method (Grewal, 1991).

The identified nematode genera were then classified by trophic group as plant parasites, fungivores, bacterivores, omnivores or predators according to Yeates et al. (1993). Each identified nematode genus was also classified along a colonizer-persister (c-p) continuum of 1 to 5 according to Bongers’s (1990) c-p scale. Nematodes with a c-p value of 1 are short lived, have high reproduction rates, and feed on enriched media whereas those of a c-p value of 5 have a long life span, low reproduction rates, and are predominantly omnivores and predators (Bongers, 1990).

2.4 Tomato Fruit Productivity Assessment

2.4.1 2011 Tomato Production Site Identification in the Gardens

Different approaches were used in 2011 and 2012 to obtain yield data on tomato productivity in the gardens. These are described below.

In 2011, each of the ten urban gardens was mapped and sections containing tomato plants for analysis were identified. Each section was measured to determine the total square meters of garden allotted to growing tomatoes. The number of tomato plants present were also counted. A ratio of garden area per plant was calculated and analyzed to ensure that plant spacing was not a significant factor affecting tomato production.

These identified sections were planted, maintained, and harvested by the gardeners. Photographic data for tomato production was collected throughout the summer. Total tomato weight harvested was recorded by gardeners.

2.4.2 2011 Tomato Photographic Counts
In the summer of 2011, starting in mid-July, tomato sections for each of the 10 garden sites were photographed sequentially every 2 to 3 weeks to create a pre-harvest estimation of yield (Bumgarner et al., 2012). Since gardens were staked approximately 1.5 meter sections, each photograph tried to encompass each staked off section. Depending on the garden, and how closely tomatoes were planted, some photographs were taken at an angle while others were taken from directly in front. Some sections involved several photographs, sometimes down to a single plant per photo, being taken to get all of the plants visibly documented via photography. Photographs were taken from one side only to prevent repeat counting of fruit that could be visible from both sides.

Photos were then visually analyzed with all green and red tomatoes counted, identified according to type (cherry versus regular sized), and then recorded by garden. Only the tomatoes from the recorded row were counted in each photograph. Which means that if a ripe or other tomato were visible, but could be determined to belong to a posterior or other row, it was not counted until the photographs from that row were analyzed.

An expected tomato weight was calculated from the known average weight of all the tomato varieties planted in each garden. This calculated average was unique to each garden as it was weighted to account for the different varieties and different number of plants of each variety within a garden. The expected tomato weight was multiplied by the number of tomatoes counted to give an estimated yield by weight for green fruit, red fruit, and total fruit for each photography date.

2.4.3 2011 Tomato Harvest Reported by the Gardeners
At the end of the growing season in 2011, the gardeners also self-reported their harvests in mass of tomatoes harvested by date. Reports including mixed types of tomatoes or unspecified unripe tomatoes were assumed to include equal masses of each size-class and variety of tomato grown within the garden. Unripe, or green, tomatoes were assumed to not include cherry tomatoes when subdivided among varieties.

Both estimated tomato yield and self-reported yields were converted to kg/sq. m and kg/plant. Self-reported yields were compiled from all reported harvest dates into a single total harvest weight before being analyzed.

2.4.4 2012 Single Variety Comparison

In the spring of 2012, tomato seedlings of the variety Celebrity were provided to the gardeners. Celebrity is a determinate variety that produces fleshy medium sized fruit. This variety was selected as the determinate nature would prevent the plants from overgrowing the smaller community garden plots, while the fruit would provide the market gardeners with a salable product. As a robust hybrid, the Celebrity variety has been bred to produce fruit in a wide range of soil conditions, making it possible that the urban garden soil conditions would not significantly affect fruit production. Because of this robustness, a variety of growth data was to be included in 2012 in addition to crop yield.

Celebrity seedlings were sown in early May and grown for 3 weeks in organic seed starter. At least 6, but up to 10, Celebrity seedlings were planted in a prepared bed at each urban garden site during the first week of June. Watering and disease control of these plants were conducted by the gardeners during the growing season. Data for plant
height, plant surface area, leaf weight and leaf surface area were collected starting on June 19, two weeks after transplanting, and continued weekly for 8 weeks. At this point, data collection switched to collecting tomato harvest on a weekly basis for the next 5 weeks. After 13 weeks, all remaining fruit on the plants were harvested, counted, and weighed.

2.4.5 2012 Celebrity Plant Parameter Measurements

In 2012, starting on June 19, two weeks after initial transplanting into the gardens, all plant growth measurements were recorded weekly for 8 weeks. Around this time, the tomato fruits were starting to mature. So, since N becomes diverted from plant development to fruit production at around 40 days after transplanting (Tei et al., 2002), it was assumed that no further changes in plant development would occur from this point onward, and the recording of growth measurement was discontinued and collection of tomato fruit production data commenced.

2.4.5.1 Plant Height

The initial height at transplanting of the 2012 Celebrity seedlings were recorded for later statistical analysis to ensure that there was no initial bias in plant height between garden sites. Plant height was collected weekly starting June 19, two weeks after transplanting. They were then compared by collection date.

2.4.5.2 Plant Surface Area

At the same time as height, surface area of the Celebrity tomato plants was measured during the summer of 2012. To determine surface area, a 1 m x 1 m wooden frame was constructed so that it could be set around each plant in the field. An aerial
photograph was then taken of each plant within the confines of the frame. Each photo was edited in Adobe Photoshop CS5.1 to delineate plant from background. Photos were then analyzed in WinCam to determine what percentage of the frame was plant versus background. Percentages were then multiplied by the interior area of the frame via

\[
\text{Surface Area of plant in square centimeter} = 8361.27 \text{ square centimeter} \times \left(\frac{\% \text{ plant surface area in WinCam}}{100}\right)
\]

to determine the square centimeter surface area of each plant. Surface area of all plants compiled by garden type from all dates was analyzed, as well as the surface area of plants by garden type within each collection date.

2.4.5.3 Leaf Surface Area

The surface area of the most recently developed mature leaf on each Celebrity tomato plant was also collected on a weekly basis during the summer of 2012. The most recently developed mature leaf was defined as the fifth most recently developed leaf, determined by counting downward from the apex of the plant. After collection, the leaves were immediately scanned into a computer so that the true size of the leaf was maintained within the digital file against a standard 6” square background. Scans were analyzed in WinCam to determine the percentage of the leaf versus background. Percentages were then multiplied by the area of the images via

\[
\text{Surface Area of leaf in square centimeter} = 232.25 \text{ square centimeter} \times \left(\frac{\% \text{ leaf surface area in WinCam}}{100}\right)
\]
to determine the square centimeter surface area of each leaf. Surface area of all leaves compiled by garden type from all dates was analyzed, as well as the surface area of leaves compiled by garden type within each collection date.

2.4.5.4 Leaf Dry Weight Ratio

The dry weight ratio of the most recently developed mature leaf was also collected on a weekly basis during the summer of 2012. The most recently developed mature leaf was defined as the fifth most recently developed leaf, determined by counting downward from the apex of the plant. After collection, the leaves were transported in a cooler back to the lab where they were weighed to determine their fresh weight. Leaves were then allowed to dry at room temperature for a week before being reweighed so that a ratio of dry to fresh weight could be determined for each plant. This ratio ensured that leaf size as a result of how long a leaf was allowed to develop before being harvested would not confound a comparison of leaves between plants. Dry weight ratio was determined by

\[ \text{Dry weight ratio} = (\text{Measured dry weight/Measured fresh weight}) \times 100 \]

The dry weight ratio of all leaves compiled by garden type from all dates was analyzed, as well as the dry weight ratio of leaves compiled by garden type within each collection date.

2.4.5.5 Tomato Harvest

Once Celebrity tomatoes had ripened enough to be classified as stage 4, pink stage, harvesting of tomatoes began. This occurred in mid-August of 2012. Each week, tomatoes that had reached stage 4 were collected. Total number of collected tomatoes,
each collected tomato’s individual weight, and the marketability of each tomato were recorded for 5 weeks, until mid-September. Tomatoes were considered unmarketable if they showed any of the following characteristics: insects burrowed into them, mold, rot, large cracks making them visually displeasing, or bites taken out of them. At the end of 5 weeks of harvest data recording, all remaining green tomatoes were collected from each plant, counted, weighed and had their marketability determined. Whole, undamaged fruit were considered marketable while damaged fruit were considered unmarketable. Cause of damage was recorded for each unmarketable tomato.

Number and weight of tomatoes were statistically compared for all tomatoes (including final green tomatoes) across all dates, for only ripe tomatoes (not including final green tomatoes) across all dates, for all collected tomatoes at each of the harvest dates, and for only marketable tomatoes at each of the harvest dates.

2.5 Statistical Analyses

Data were analyzed in Minitab 15 (Minitab, Inc., State College, Pennsylvania). All data were checked for normality with the Ryan-Joiner Test for Normality. Data that were normally distributed were then subjected to ANOVA. Data that were not normally distributed were transformed until they achieved a normal distribution. Soil moisture and texture values were normally distributed. SOM was transformed to the square root of the calculated values for further analysis. The $\text{NH}_4^+$ and $\text{NO}_3^-$ data were transformed by natural log to achieve normalization, while the square root of DON and MBN were the appropriate transformations. Nematode community counts were transformed via natural log for normalization before being analyzed. Untransformed nematode c-p and trophic
population counts were used to calculate various nematode food web indices (Bongers, 1990; Ferris et al., 2001). The Maturity Index (MI), a Plant Parasitic Index (PPI), a Combined Maturity Index (which includes both the MI and PPI), and Non-Plant Parasitic/Plant Parasitic Nematode ratio were calculated as follows:

\[
MI = \sum (\text{Each non-plant parasitic trophic group} \times \text{its c-p value}) / \text{total non-plant parasitic nematodes}
\]

\[
PPI = \sum (\text{Each Ppn group} \times \text{its c-p value}) / \text{total Plant Parasitic nematodes}
\]

Combined MI = \sum (\text{Every trophic group} \times \text{its c-p value}) / \text{total nematodes}

\[
N-PPN/PPN = \text{total Non-Plant Parasitic nematodes} / \text{total Plant Parasitic nematodes}
\]

These indices data were normally distributed and were therefore not transformed.

Finally, Enrichment Index (EI), Structural Index (SI) and Channel Index (CI) were calculated by determining the basal, the enrichment and the structural values for the food web based on the untransformed identified nematode counts. These three values were determined according to the present trophic groups being multiplied by a constant identified by Ferris et al. (2001) by

\[
\text{Basal} = (0.8 \times FF_2) + (0.8 \times BF_2)
\]

\[
\text{Enrichment} = (3.2 \times BF_1) + (0.8 \times FF_2)
\]

\[
\text{Structure} = (0.8 \times CA_2) + (5.0 \times OM_5) + (1.0 \times BF_3) + \ldots
\]

and

\[
\text{Enrichment Index} = 100 \times [\text{Enrichment} / (\text{Enrichment} + \text{Basal})]
\]

\[
\text{Structural Index} = 100 \times [\text{Structure} / (\text{Structure} + \text{Basal})]
\]

\[
\text{Channel Index} = 100 \times [(0.8 \times FF_2) / (3.2 \times BF_1 + 0.8 \times FF_2)]
\]
In addition to graphing the untransformed EI and SI to obtain a visual representation of the faunal profile, the calculated EI and SI were transformed by taking the square of the data, while the log of the CI was taken to achieve a normalized distribution.

All pre-harvest yield estimates and reported tomato fruit yield data from the summer of 2011 were normally distributed and did not undergo transformation.

The 2012 tomato growth data treatment depended on the growth parameter being analyzed. The plant height data were normally distributed. The plant surface area data was normally distributed for data collected on June 4, but the square root of all subsequent dates was taken to achieve normalization. The leaf surface area of the leaves collected on June 19, July 5, July 19, and July 26 were also normally distributed. The leaf surface area of leaves collected on June 28, July 12, and August 2 were transformed by taking the square root before being analyzed.

P < 0.05 from the General Linear Model ANOVA comparison was considered significantly different. Means and standard errors were calculated in Excel, with mean separation achieved by Tukey’s test.

All figures and tables contain untransformed data. Faunal profiles were created in Excel by graphing the SI on the x-axis and the EI on the y-axis to create a visual representation.

Untransformed data were subjected to Pearson’s for correlation analysis. This analysis was used to determine if age of the gardens influenced soil parameters in both 2011 and 2012. In 2011, correlation analysis was also performed between reported yield and soil and nematode parameters. In 2012, correlation analysis was performed between...
Celebrity tomato growth parameters and total fruit yield and soil and nematode parameters.
3.1 Comparison between Community Gardens and Market Gardens

3.1.1 Soil Moisture and SOM

There was no difference in soil moisture between community and market gardens in the summer of 2011 (Figure 2). However, the market gardens had higher SOM than the community gardens (F=41.53; P=0.000; df:1). There were differences in both parameters in 2012. The market gardens had both a higher soil moisture (F=12.38; P=0.001; df:1) and SOM content (F=10.76; P=0.001; df:1) than the community gardens.

3.1.2 Soil Texture

There were no significant differences in sand, silt and clay contents between community and market gardens (Figure 3).

3.1.3 Soil Nitrogen (N)

During the summer of 2011, the market gardens had significantly more NH$_4^+$ (F=10.47; P=0.002; df:1), NO$_3^-$ (F=13.55; P=0.000; df:1), DON (F=9.27; P=0.003; df:1) and MBN (F=8.78; P=0.004; df:1) than the community gardens (Figure 4). In 2012, there were no significant differences between NH$_4^+$, NO$_3^-$ or DON fractions in the community and market gardens. However, the market gardens had significantly more MBN than the community gardens (F=29.05; P=0.000; df:1) (Figure 4).

3.1.4 Soil Nematode Food Web Analysis
In 2011, there was a significantly greater total number of nematodes in the market gardens (F=10.35; P=0.002; df:1) compared to the community gardens (Figure 5). Of this total number of nematodes, there were greater numbers of the bacterivore (F=4.61; P=0.034; df:1) and the omnivore (F=4.93; P=0.029; df:1) trophic groups (Figure 5). There was no significant difference between fungivore, plant parasitic or predatory nematode trophic groups between the community and market gardens. Also, there was no difference in MI, Combined MI, EI, or SI between the two garden types (Figure 6 and Figure 7). The CI was greater in the market gardens (F=6.10; P=0.016; df:1) compared to the community gardens (Figure 7).

In the 2012, there was again a significantly greater total number of nematodes in the market gardens (F=7.38; P=0.008; df:1) compared to the community gardens (Figure 5). There were also more genera present in the market gardens compared to the community gardens (F=6.02; P=0.016; df:1) (Figure 5).

There were also greater numbers of bacterivore (F=10.45; P=0.002; df:1) and plant parasitic nematode (F=6.08; P=0.016; df:1) trophic groups in the market gardens compared to the community gardens, but there were no differences in fungivore, omnivore or predatory nematode trophic groups. Additionally, the combined MI was higher for the community gardens than the market gardens (F=4.22; P=0.045; df:1) (Figure 6). As opposed to 2011, in 2012 the CI was greater for the community gardens than the market gardens (F=5.66; P=0.019; df:1) (Figure 6).

The faunal profiles for both garden types were classified by high enrichment and low structure indices (Figure 8). Given these characteristics, and the low CI values for the
gardens, the decomposition processes are bacteria driven in both community and market gardens.

3.1.5 2011 Tomato Photographic Counts

The pre-harvest yield indicated two different conclusions, depending on how the data were processed. The counted number of tomatoes per square meter did not show a difference between the garden types. However, after the tomato counts were converted to estimated weights by cultivar, a significantly greater yield of tomatoes was found in the community gardens compared to the market gardens in 2011 (Figure 9).

3.1.6 2011 Reported Tomato Fruit Yield

There was no significant difference in reported tomato yield between market and community gardens during the summer of 2011 (Figure 10).

3.1.7 2012 Celebrity Tomato Plant Height

During the summer of 2012, there was no difference in plant height between the Celebrity plant seedlings grown in market versus community gardens at the time of transplanting or at any of the subsequent dates data were collected (Figure 11).

3.1.8 2012 Celebrity Tomato Plant Surface Area

Overall, the surface area of the 2012 community garden grown plants was larger than for market garden grown plants (F=4.08; P=0.044; df:1) (Figure 12). However, when looking at individual dates, only the surface area of the seedlings on June 19 were significantly larger in the community gardens compared to the seedlings in the market gardens (F=6.85; P=0.011; df:1) (Figure 12). This difference disappeared by June 28 and this trend continued at each individual date for the rest of the data collection period.
3.1.9 2012 Celebrity Tomato Leaf Surface Area

Overall, the leaf surface area of community garden grown plants was larger than for market garden grown plants ($F=6.55; P=0.011; df:1$) (Figure 13). When comparing plants at specific collection dates, the leaf surface area of the plants was significantly larger for the community garden plants on June 19 ($F=5.88; P=0.020; df:1$) and July 12 ($F=44.29; P=0.000; df:1$) (Figure 13).

3.1.10 2012 Celebrity Tomato Leaf Dry Weight Ratio

When comparing all leaf dry weight ratios over all dates, the community gardens had a significantly greater dry leaf weight ratio than market gardens ($F=6.55; P=0.011; df:1$) (Figure 14). Upon a date by date comparison, the leaf dry weight was significantly greater for community garden plants compared with the market garden plants on July 19 ($F=8.06; P=0.006; df:1$) and August 2 ($F=4.01; P=0.050; df:1$) (Figure 14).

3.1.11 2012 Celebrity Tomato Tomato Fruit Yield

There were no significant differences between garden types for total tomato fruit yield, number of total fruit per square m, number of marketable fruit per square m, average weight of total fruit per square m, or average weight of marketable fruit per square m (Figure 15).

3.2 Comparison of Gardens with Raised Beds vs. Gardens with Flat Beds

3.2.1 Soil Moisture and SOM

In both 2011 and 2012, gardens with raised beds had a significantly higher moisture content (2011: $F=6.95; P=0.010; df:1$, 2012: $F=17.54; P=0.000; df:1$) and SOM
content (2011: $F=36.76, P=0.000; df:1$, 2012: $F=35.46, P=0.000; df:1$) than gardens with flat beds (Figure 16).

3.2.2 Soil Texture

There was no difference in sand, silt and clay contents between gardens with raised beds and gardens with flat beds (Figure 17).

3.2.3 Soil Nitrogen (N)

In 2011, gardens with flat beds had significantly greater $\text{NH}_4^+$ than gardens with flat beds ($F=5.64; P=0.020; df:1$). In 2012, gardens with raised beds had significantly greater $\text{NH}_4^+$ ($F=3.90; P=0.050; df:1$) and MBN ($F=8.87; P=0.004; df:1$) than gardens with flat beds (Figure 18).

3.2.4 Soil Nematode Food Web Analysis

In 2011, there was a significantly greater total number of nematodes in gardens with raised beds ($F=8.62; P=0.004; df:1$) than in gardens with flat beds. Of this total number of nematodes, there were greater numbers of fungal feeding ($F=4.91; P=0.029; df:1$) nematodes in the gardens with flat beds, but greater numbers of plant parasitic ($F=5.01; P=0.028; df:1$), and omnivore ($F=9.16; P=0.003; df:1$) nematodes in the gardens with raised beds (Figure 19). There were no significant differences between bacterivore or predatory nematode tropic groups in the two production systems.

The MI ($F=9.11; P=0.003; df:1$) and Combined MI ($F=5.65; P=0.020; df:1$) index values in 2011 were significantly higher for gardens with raised beds than gardens with flat beds (Figure 20). The SI was also higher in gardens with raised beds ($F=8.99;
P=0.004; df:1), but the EI was higher in gardens with flat beds (F=5.48; P=0.022; df:1) (Figure 21). There was no difference in the CI values.

In 2012, there was a greater total number of nematodes (F=4.23; P=0.043; df:1) present in the gardens with raised beds, but only the bacterivore trophic group showed significantly higher numbers in gardens with raised beds compared to gardens with flat beds (F=7.21; P=0.009; df:1) (Figure 20). There were no differences in number of genera or any of the other trophic groups. There was no difference in MI, PPI, Combined MI, SI, EI or CI between the production methods in 2012.

3.2.5 2011 Tomato Photographic Counts

In 2011, there was no significant difference in pre-harvest estimate by fruit count or by conversion to estimated weight when comparing gardens with raised beds to gardens with flat beds (Figure 22).

3.2.6 2011 Tomato Fruit Reported Yield

There was no significant difference in reported fruit yield in 2011 when comparing gardens with raised beds to gardens with flat beds (Figure 23).

3.2.7 2012 Celebrity Tomato Plant Height

During the summer of 2012, the height of plants in gardens with raised beds were significantly greater (F=4.93; P=0.027; df:1) than those in gardens with flat beds (Figure 24). When comparing plants at specific collection dates, the plants grown in gardens with raised beds were significantly taller on June 19 (F=3.52; P=0.065; df:1) and August 2 (F=4.07; P=0.048; df:1).

3.2.8 2012 Celebrity Tomato Plant Surface Area
The surface area of plants grown in gardens with raised beds was larger than for plants grown in gardens with flat beds (F=16.78; P=0.000; df:1) (Figure 25). When comparing individual dates, there was no specific date at which gardens with raised beds had a greater plant surface area than gardens with flat beds.

### 3.2.9 2012 Celebrity Tomato Leaf Surface Area

The leaf surface area of plants grown in gardens with raised beds was also larger than those of plants grown in gardens with flat beds (F=6.99; P=0.009; df:1) (Figure 26). When comparing leaf surface area at individual dates, the leaves from plants grown in gardens with raised beds were significantly larger on June 28 (F=4.54; P=0.038; df:1) and July 15 (F=8.26; P=0.006; df:1).

### 3.2.10 2012 Celebrity Tomato Leaf Dry Weight Ratio

The leaf dry weight ratio was greater for plants grown in gardens with flat beds (F=13.89; P=0.000; df:1) than those plants grown in gardens with raised beds (Figure 27). Upon a date by date comparison, the leaf dry weight was significantly greater for leaves from plants grown in gardens with flat beds on July 12 (F=14.28; P=0.000; df:1) and July 19 (F=9.49; P=0.003; df:1).

### 3.2.11 2012 Celebrity Tomato Tomato Fruit Yield

There was no significant difference between gardens with raised beds and gardens with flat beds for total tomato fruit yield, number of total fruit per square meter, number of marketable fruit per square meter, average weight of total fruit per square meter, or average weight of marketable fruit per square meter when comparing all tomatoes harvested, or all ripe tomatoes harvested (Figure 28).
3.3 Correlation Analyses

There was no consistent relationship between the age of the gardens and the soil properties in the gardens between 2011 and 2012 when comparing all of the gardens, the gardens with flat bed production systems, or the gardens with raised bed production systems (Table 2).

Significant negative correlation was found between the 2011 reported tomato fruit yield and NH$_4^+$ and DON, and bacterivore trophic group as well as MI (Table 3). The 2012 Celebrity plant growth parameters showed negative correlations with nematode indices of MI, Combined MI, EI and CI, however the 2012 Celebrity yield was not correlated with the soil or nematode parameters (Table 3).
Chapter 4: Discussion

The raised bed gardens had much higher SOM content than those with flat beds. This trend also carried over into the community versus market garden comparison, as the market gardens predominately consisted of gardens with raised beds (Table 1), and also showed a significantly greater SOM content in both 2011 and 2012. Although it has been shown that older urban areas tend to have higher SOM than newly established urban areas (Park et al., 2010), the younger market gardens and gardens with raised beds had higher SOM content. Still, there was no consistent correlation between SOM and the age of the gardens (Table 2), so the difference in SOM between garden types cannot be attributed primarily to soil erosion or weathering processes over time reducing the top layer of cultivatable soil or to time since disturbance allowing soil processes to recover. This suggests that the soil amendments applied to the raised beds are likely the source of this greater SOM content and, through the process of building raised beds, the market gardeners invested in a greater amount of SOM than the community gardeners.

The greater SOM as a result of raised beds did coincide with the maintenance of compost bins on the garden site. All but one of the market gardens that had raised beds also maintained compost bins. The only community garden with raised beds also had gardeners collectively maintain on-site compost bins, while the other community gardeners that did not use raised beds applied compost from an external provider through
the OSU Extension system. Although, the maintenance of composting bins requires an investment of labor to manage the composting plant material, the correlation between compost bins and raised beds in gardens suggests that the on-site availability of compost might offset other costs of creating raised beds full of SOM to improve the soil health.

Soil core sampling occurred in June after the compost and/or animal manures had already been worked into the soil during the spring soil preparation. Thus, all N measurements should be a result of the initial soil amendment and subsequent mineralization process. In 2011, the greater presence of all forms of N in the market gardens mirrored the greater SOM present in the market garden soil, although in 2012 only the MBN in the market gardens was associated with the greater SOM present.

Comparing the gardens with raised beds and gardens with flat beds in 2011, the only significant difference in N content was \( \text{NH}_4^+ \), and it was higher in gardens with flat beds – which had lower SOM. Conversely, in 2012, the gardens with raised beds had higher SOM, \( \text{NH}_4^+ \), and MBN. This difference between results obtained in 2011 and 2012 could be attributed to several factors other than SOM content, such as planting date, weather conditions, and/or soil community activity.

The year 2011 was warm, with an average temperature of 21°C during the spring, and also the wettest year on record for Cleveland, with 51 cm of rainfall by June 1st (Exner, 2012a; National Weather Service Forecast Office, 2012; OARDC Weather System, 2012) (Figure 29). By comparison, while 2012 was the hottest on record, the spring season was also one of the driest, with only 20 cm of rainfall between March 20th and July 13th (Exner, 2012b; OARDC Weather System, 2012) (Figure 29).
The warm, wet spring of 2011 could have led to early planting. Conversely, in 2012, the dry conditions could have delayed planting until a time when the weather conditions could become more favorable before the year’s crop was committed to being planted. This could result in plants being in the ground and consuming N for a longer period of time before soil sampling occurred in 2011 than in 2012. This potentially longer planting period could also increase the rate of N mineralization by increasing time for competition between the plant and soil community, stimulating the soil community to mineralize more N to compensate for the amount the plant community consumes.

The weather’s potential direct impact on N levels relates to Chae and Tabatabai’s (1986) findings that manure and other soil amendments exhibit an incubation lag period after being added to soil before N mineralization starts to occur. Since increases in temperature and moisture stimulate microbial activity and result in quicker substrate decomposition (Alon & Steinberger, 1999; Cookson et al., 2007; Waldrop & Firestone, 2004), the warm and moist weather in the spring of 2011 would have greatly stimulated N mineralization and consumption. The 2011 rainfall would also readily transport the inorganic N forms through the soil to areas where it could be consumed by plants and soil organisms. These rainfall and temperature were different in 2012 when irrigation would be the main moisture stimulant, and one not able to mimic the torrential rainfall of the previous year. The hot and dry summer in 2012 would have increased the incubation lag period and slowed mineralization by the soil community compared to 2011.

Although the market gardens had a greater abundance of total nematodes in both 2011 and 2012, this was reflected in a greater abundance in more trophic groups in 2011,
and a greater number of genera in 2012. Meanwhile, the gardens with raised beds also had a greater abundance of total nematodes in both 2011 and 2012, but no difference in number of genera (Figure 19). The initial concern here is that some variation in soil sampling between years could have impacted the nematodes. However, de Goede and Bongers (1994) found that variation in soil data as a result of the sampling and handling of soils was minimal compared to the inherent differences in nematode populations between sites as long as the same soil horizons were collected for comparison.

Since the gardens had similar physical management practices of turning in fresh soil amendments in the spring, then they would not have soil horizons, per se, but rather a similar soil structure that would be present in all gardens to sample from. The gardens, whether compared by garden type or gardening system, also had similar soil textures, which can influence nematode food webs through preferential locomotion by particular species and should have promoted similar nematode food webs in both types of gardens (Yeates et al., 1991). Therefore, these characteristics cannot account for the differences in the nematode food webs.

The nematode EI, SI and CI illustrate what forces are shaping the soil community in the urban gardens. When comparing community and market gardens, the EI value for both garden types is high, reflecting the high nutrient content “enriching” the soil food web. This abundance of available nutrients comes from the soil amendments added in by the gardeners, and are stimulating the populations of quick growing colonizer nematodes. The SI value for both garden types is low, which is to be expected in highly disturbed agricultural soils. The soil is often broken or dug into as crops are planted, weeded, and
harvested. This disturbance is reflected in the lower structure of the nematode food web by impacting the survival of disturbance sensitive persister nematodes.

When comparing garden production systems, in 2011 the gardens with raised beds had a significantly greater SI while the gardens with flat beds had a significantly greater EI. The greater SI indicates that the raised beds somehow coincided with the survival, colonization or development of persister nematodes when compared to gardens with flat beds. This is unexpected as the creation of raised beds should have disturbed the soil, resulting in little nematode population structure being present. Similarly surprising was how the lack of raised beds somehow related to a greater nutrient enrichment of the soil for colonizer nematodes to respond to, when compared to gardens with raised beds.

The low CI values for both gardens indicate that both the community and the market gardens have decomposition pathways that are mediated heavily by bacteria, rather than fungi (Ferris et al., 2001; Neher et al., 2004). Since the EI and SI already establish the environment as one of high nutrient availability and high disturbance, it is to be expected that bacteria with their small size and quick reproductive rates are better suited than fungi to mediate the decomposition pathway in disturbed agricultural soils.

The MI, PPI and Combined MI all measure the extent of the impact of disturbance in the environment or the soil food web (Bongers, 1990; Neher et al., 2004). The values for all three indices are on the lower end, indicating high environmental disturbances affecting the nematode food web in both community and market gardens, as well as gardens with raised beds and gardens with flat beds. The Combined MI in 2012 is significantly higher in the community gardens than in the market gardens. The lower
value in the market gardens suggests that it was undergoing greater microbial activity as
the increase of activity would stimulate the lower nematode trophic levels that respond to
increased microbial activity. This difference is not reflected in the comparison of gardens
with raised beds to those with flat beds.

It is interesting to note on the faunal profile depiction that two of the six market
gardens, gardens 5 and 7, had fairly high SI values compared to all of the other gardens in
2011 (Table 1) (Figure 8). However, their placement on the 2012 faunal profile did not
show the same stark difference from the other gardens. Garden 7 again had the highest
structure value while garden 5’s structure dropped to match two of the other market
gardens (Figure 8). While their particular physical management practices in 2011 could
not be differentiated from general management practices, they were at one point able to
minimize environmental disturbance, allowing more persister nematodes to establish.

Applying the typical “bottom-up” trophic pressure model to the food webs
described by the indices above, the microbial population must consume N and carbon (C)
from SOM and increase its own biomass, releasing inorganic N that will promote plant
growth. The bacterivore trophic group benefits from the abundant population of bacteria
while the plant parasitic trophic group benefits from the enhanced plant growth. The
omnivore trophic group response will lag behind these lower trophic levels as they are
more persister and less colonizer in nature and thus slower to populate, and the predatory
trophic group will be the last to increase in population (Bulluck et al., 2002; Ferris &
Matute, 2003). Although the nematodes are not being directly stimulated by the SOM,
they are reacting to the shifts in bacterial and fungal communities mediated by SOM.
Evidence for this chain reaction being based on the presence of SOM is that in studies where chemical, rather than organic, N fertilizers have been applied to soils there are marked decreases in nematodes across some or all trophic levels (Cheng et al., 2008; Hu & Cao, 2008; Todd, 1996). The use of compost and manure as the source of SOM and N gives a possible added benefit to crop management in that these amendments release nematicidal compounds when they decompose (Oka, 2010). This is a potential benefit because it is not certain whether these compounds affect only the plant parasitic trophic group or work as general nematicides. Some have been found to target plant parasitic, but not bacterivore nematodes, which may also explain the lower plant parasitic nematode presence compared to bacterivores although they compromise similar low positions on the trophic group scale (Browning et al., 2004; Lazarovits, 2001; Rodriguez-Kabana, 1986; Rodriguez-Kabana et al., 1987).

In both community and market gardens, and in both years, the bottom-up pressures do not affect the fungal feeder trophic group. However, when comparing gardens with raised beds and gardens with flat beds in 2011, the fungal feeder trophic group is significantly greater in the less disturbed gardens compared to gardens with raised beds. The building of a raised bed requires extensive physical disturbance such as tilling or turning or piling of soil in an area, all of which can break or impede fungal hyphae growth in the soil, resulting in reduced fungal feeding nematode populations.

Similar to the argument for why differences occurred between the 2011 and 2012 N values, the nematode population differences could also be traced to differences in planting date, or weather conditions. The assumption for 2011 is that an earlier planting
date could have altered the nematode community, even though the soil sampling date for nematodes had not changed. The longer plant establishment period would allow the 2011 crops to better develop their root systems in the soil. If there were some set of preferred soil conditions for nematode development that were contingent on the presence of plant roots, then there would be a longer period of time in 2011 for these conditions to occur and promote the development of a more robust and diverse nematode food web. Similarly, if 2012 had a later planting date, then the soils would be disturbed closer to the soil collection date than the 2011 soils. Thus, it would be expected that the lower trophic levels that follow the colonizer model would be the only nematodes to result in significant differences between the gardens during this shortened recovery period as the other trophic groups would not have had time to establish populations of sufficient size to show differences (Freckman & Ettema, 1993; McSorley, 1997; Neher & Lee Campbell, 1994).

The lower nematode abundance in the hot and dry 2012 season could also be due to the high sensitivity of nematodes to rainfall in terrestrial environments (McSorley, 1997). Or, if we consider “bottom-up” trophic pressures, they may be sensitive to how the soil microbial community reacts to rainfall; so, if the microorganism community is impeded by the dry conditions, the nematode food web will also be affected (Birch, 1960). Another “bottom-up” pressure could originate with the tomato plants and how the tomato plants responded to the different weather conditions in each year. There is a commensal relationship between the soil community providing nutrients to plants in exchange for sugars secreted through the roots. So, if the tomato plants were not able to
supply as many root exudates in 2012 as they had in 2011, then this is another way in which the soil food web could be impacted.

Plant growth research on N availability (Abdul-Baki et al., 1997; Ganmore-Neumann & Kafkafi, 1980; Locascio et al., 1992; Tei et al., 2002) has determined that the optimal N value is between 44.6 to 89.3 ppm (Tei et al., 2002), although other studies preferentially recommend specific concentrations within that range (Doorenbos & Kassam, 1979; Hochmuth, 1988; Maynard & Hochmuth, 1995). In 2011, the market gardens had a combined NH$_4^+$ and NO$_3^-$ concentration close to 40 ppm, while the community gardens had a combined NH$_4^+$ and NO$_3^-$ concentration that was half of that. This difference in plant available N in 2011 should be reflected in the total yield from crops; however, there was no difference in the season’s yields reported by the gardeners.

The 2011 photographic pre-harvest analysis also showed no difference in the abundance of tomatoes in the fields during the growing season by garden type or by garden preparation. Only when the photographic pre-harvest was converted into the estimated weight of tomatoes in the fields during the growing seasons did a significant difference between garden types appear – with the community gardens having more tomato mass. And yet when the 2011 pre-harvest estimate of weight was compared between gardens with raised beds to gardens with flat beds, there was no significant difference between production systems.

A point of note is that the tomato varieties planted in 2011 varied greatly from garden to garden. Some examples of the varieties grown were Valencia (1 garden, 0.26 kg/fruit), Magic Mountain (3 gardens, 0.07 kg/fruit), Rutgers Hybrid (1 garden, 0.14
kg/fruit), Wapsipinicon Peach (1 garden, 0.06 kg/fruit), Early Girl (2 gardens, 0.17 kg/fruit) and Supersonic (1 garden, 0.26 kg/fruit) (Table 4). These widely different weights were proportionally weighted by how many plants of each variety were grown in each garden, and then combined to create a single conversion value for turning the total number of fruit counted in the pre-harvest photos into a weight of fruit for each photography date. Variation between how many of each variety were counted numerically versus proportionally weighted in the conversion factor could have mistakenly resulted in a mistaken significant difference for photographic calculated weights, even though neither photographic fruit count nor reported yield showed a significant difference in total fruit yield between garden types.

When considering the lack of correlation between the calculated N values and the subsequent tomato yield, a possible explanation may be that the N levels in the soil continued to be regulated by soil community activity and either remained constant or increased as the season progressed. The soil samples were collected near the beginning of the growing season, so the soil N pools indicated the early growing conditions for plants. The correlation analysis at this time showed a negative correlation between the 2011 fruit yield, and NH$_4^+$, DON, total number of nematodes and number of bacterivores present, suggesting that high levels of NH$_4^+$ and DON promote utilization of these resources by the soil community, preventing plants from having greater yields as a result of greater available NH$_4^+$ and DON (Table 3). And later seasonal changes in plant-available N as a result of increase in mineralization or as a result of a decrease in competition could have surpassed the N recommendation in both garden types by the time fruiting occurred, since
N becomes diverted from plant development to fruit production at around 40 days after transplanting (Tei et al., 2002). This would result in there being no discernible difference of N between the garden types or garden preparation methods that could cause a measurable yield difference.

The difficulty in ascertaining the source of the lack of difference in yield in 2011 inspired the inclusion of a common tomato variety, Celebrity, across all gardens in the summer of 2012. The plant available N concentration in June 2012 was only about 18 ppm for both garden types. As the tomato plants did not show signs of severe N stress such as noticeably small and thick leaves (Scholberg et al., 2000), it is assumed that N cycling continued through the growing season to provide a sufficient amount of N availability so that the plants were able to develop properly.

As the Celebrity plants developed in 2012, it was noted that the leaf dry mass, the leaf surface area, and the plant surface area of the community garden grown tomato plants were greater than the market gardens. And yet, comparison by garden production system showed the plants in the gardens with raised beds had greater height, plant surface area and leaf surface area than plants in the gardens with flat beds while the leaf dry mass ratio was greater for the plants in gardens with flat beds. The difference in plant growth parameters in 2012 between garden types could not be the result of only greater N stimulating plant growth as there had been no significant difference in NH\textsubscript{4}\textsuperscript{+} or NO\textsubscript{3}\textsuperscript{-}, the two N types readily available for plant uptake, between the community and market gardens. However, a comparison by garden production system does show both greater NH\textsubscript{4}\textsuperscript{+} and greater plant growth parameters for the gardens with raised beds. So, while
there could be a relationship between N and plant growth when looking at the presence or lack of raised beds, there is no such relationship for the comparison by garden type. Since raised beds, which had the greater SOM present, were used in only one community garden, it is unlikely that increased nutrient availability from SOM could be the main reason for why community gardens showed a greater plant growth response, even though the gardens with raised beds also had the greater plant growth response.

Another management factor that could factor in to the different plant growth response in community and market gardens could be watering frequency. The year 2012 had a hot and dry summer. While some market gardens were laid with drip tape for direct irrigation, all market gardens were staffed daily with workers who would make sure plants were adequately watered. The community garden plants did not have such a regular watering interval and instead were dependent on the schedules and availability of gardeners for watering. If watering were delayed such that partial wilting occurred, then when the community garden plants were next watered, a typical post-wilting-stress growth spurt (Gates, 1955) could account for the larger surface areas for these plants.

An indirect factor influencing the 2012 Celebrity plant growth parameters could be the soil community activity levels as measured by the nematode food web. Both the MI and Combined MI record nematode activity as a response to increased microbial activity. The MI was negatively correlated with both plant height and leaf surface area while the Combined MI was negatively correlated with plant height, plant surface area and leaf surface area (Table 3). The CI, which indicated high levels of bacterial decomposition across all the gardens, was also negatively correlated with all three plant
growth parameters (Table 3). So, similar to the negative correlations in 2011 between greater numbers of nematodes and bacterivore nematodes that would benefit from a greater presence of bacteria, high levels of bacterial activity in 2012 is negatively correlated with crop growth and development, probably as a result of competing for similar resources. Still, the EI did correlate with leaf surface area (Table 3), suggesting that the plants did benefit from nutrient enrichment as a form of disturbance.

Similar to the 2011 tomato fruit yield results, there was no difference in the number or weight of tomatoes produced by the 2012 Celebrity tomato plants. There was also no difference in the number or weight of marketable tomatoes between the garden types or garden production methods. The horticultural management practices used in all of the gardens were generally similar, so there may not have been great enough differences in the soil chemical properties and the soil community profiles to show up in the fruit yield of a variety, like Celebrity, that has been bred to show consistent fruit yield in a range of environmental conditions. Additionally, there are a number of environmental conditions that could have influenced fruit development that were not able to be monitored well enough to determine whether they affected fruit yield more than the soil properties and soil community profile.

The first step of tomato fruit development, flower setting, is triggered by a combination of nutrient availability and chemical triggers within the plant itself. While soil nutrient content was measured, it was done so at the beginning of plant growth, and may have changed by the time the tomato plants were preparing to develop fruit. Once the flowers are available to be pollinated, the pollen must survive long enough to self
pollinate the flowers. Temperatures of 32°C sterilize or prevent pollination (Johnson & Hall, 1953), and much of July, when the fruits were being developed was around or above this temperature threshold and could have impacted the number of fruit that could begin the growth process. Once growing, the tomato plants would need plenty of moisture to channel into their fruit, which consist of 94% water (Bastin & Henken, 1997), but monitoring the moisture available to plants during fruit growth and maturation, like the other parameters mentioned here, were beyond the scope of this study.

One interesting point of variation that was recordable in the tomato yield is the reasons behind tomato fruit being considered unmarketable. There were four categories of damage observed during harvest: 1) tomato fruits were cracked where the skin burst open during the growth process, 2) mold was growing on the side of the fruit, either promoting or as a result of rot, 3) insects had burrowed into the fruit making it undesirable, and 4) an animal had taken a bite out of, but had not entirely consumed, the fruit. There was no difference in the occurrence of cracked fruit or of insect damage between the garden types or garden production systems noted (Table 5). However, herbivory was only observed in the market gardens, while mold damage was twice as likely to occur in the community gardens (Table 5).

This rate of damage may be related to the physical layout and management practices of each garden type. The layout of community gardens results in a patchwork of different species of plants found in many different locations throughout the whole garden. Thus, if an herbaceous mammal were to approach the garden, it would be more likely to find a desirable fruit to consume at one of the edge sites of the whole garden – far away
from the randomly located growing sites of the Celebrity tomatoes. Conversely, the market gardens clustered their types of produce together. Thus, if an animal were to approach the market garden, it would be as likely to consume a Celebrity tomato as it would any other tomato variety planted in the garden.

The higher occurrence of mold may be related to the method of how water was administered to the plants. Community gardeners exclusively used a sprinkler to water the plants whereas half of the market gardeners used sprinkler or hand watering systems while the other half had installed drip tape. The sprinkler system of watering would soak the leaves and fruit of the tomato plants in addition to watering the ground while drip tape transports water directly to the ground, without wetting the above ground portion of the plant. The extra wetting of the leaves and fruit of the tomato plants would promote mold growth in the gardens relying on hand watering. And the percentage of mold damaged fruit related nicely with the community and market gardens that used each watering system.
Chapter 5: Conclusion

While higher levels of SOM were related to higher N pools and a greater abundance of nematodes in both market versus community gardens and gardens with raised beds versus those with flat beds, the inconsistency of trends across these data suggests that there are other factors influencing these parameters. The drastically different weather conditions between 2011 and 2012 could have impacted both N mineralization rates and the nematode food web by reducing the presence of the soil community and thereby slowing mineralization and impacting the “bottom-up” food source of the nematode community.

There was no correlation between N pool values and tomato fruit yield in 2011 or 2012, for either garden type or production system. This could have been from sufficient nutrients being present in all gardens, so that greater nutrient availability in market gardens or gardens with raised beds did not lead to observable increases in yield. While the photographic pre-harvest estimate of tomato weight did indicate that there was a greater pre-harvest estimate of weight in community gardens compared to market gardens, this was not reflected in the raised bed versus flat bed comparison. This was likely due to the pre-harvest estimated weight being calculated according to the different varieties of tomato cultivars with widely different average fruit weights being grown in each garden.
Meanwhile, community gardens had higher measurements than market gardens for the growth parameters collected for the 2012 cultivated Celebrity tomato plants, yet the gardens with raised beds had higher measurements than gardens with flat beds for these same growth parameters. The lack of similar trends between market gardens and gardens with raised beds as well as community gardens and gardens with flat beds suggests that it is not just soil management but some other management practice, perhaps irrigation system or some other unrecorded management practice, that predominantly influences crop growth in these urban systems.

Overall, it seems that those gardeners who work in market gardens or create raised bed systems develop soil with better chemical and biological characteristics, although these improvements do not extend into observable differences in crop yield between garden types or production systems. However, whether these improved chemical and biological soil characteristics are caused by collective management as a market garden and/or having raised beds, or they merely associated with them but are caused by other management practices associated with market gardens and/or raised beds, is uncertain and in need of further study. Also, the lack of correlation between improved soil characteristics and increase of crop production also needs additional study to determine if this is because the soil characteristics change as the growing season progresses or if there are additional management practices that prevent crop yield differences from being observed.

If further study cannot find another mechanism beyond soil nutrient availability acting in the urban gardens, then it is recommended that the amount of costly soil
amendment added to the urban soils be reduced to a threshold amount where expense of purchasing amendments is balanced by the gain of observed increased tomato fruit yield.
Figure 1: A visualization of the soil food web by nematode faunal analysis (Ferris et al. 2001). The c-p guilds consist of Baₓ (bacterivores), Fuₓ (fungivores), Omₓ (omnivores) and Caₓ (carnivores or predators) with a valuation from 1-5 for x. The environmental conditions (basal, structure, and enrichment) for analysis are clustered with weights listed in parentheses.
Table 1: List of gardens included in the study and related information including garden type, year established, garden size, and specific management practices utilized within the garden.
Figure 2: Mean (± SE) of percent soil moisture and percent soil organic matter by garden type and year. Significant differences between community gardens (C) and market gardens (M) in each year at p < 0.05 are indicated by (*).
Figure 3: Mean (± SE) of soil texture by garden type. Significant differences between community gardens (C) and market gardens (M) at $p < 0.05$ are indicated by (*).
Figure 4: Mean (± SE) of soil nitrogen pools and microbial biomass N by garden type and year. Significant differences between community gardens (C) and market gardens (M) in each year at p < 0.05 are indicated by (*).
Figure 5: Mean (± SE) of soil nematode abundance by trophic group, garden type and year. Significant differences between community gardens (C) and market gardens (M) in each year at $p < 0.05$ are indicated by (*).
Figure 6: Indices (mean ± SE) for nematode community in community gardens (C) and market gardens (M) by year at p < 0.05 are indicated by (*).
**Figure 7:** More indices (mean ± SE) for nematode community in community gardens (C) and market gardens (M) by year at $p < 0.05$ are indicated by (*).
Figure 8: Faunal profiles of the nematode food web in community gardens and market gardens by year depicting structure and enrichment indices. Numbers indicate where each garden listed in Table 1 fall in the faunal profile.
Figure 9: Estimated mean (± SE) of 2011 abundance of tomato fruit as calculated by number of tomatoes counted in pre-harvest photographs (top), and conversion to estimated weight calculated from number of tomatoes in pre-harvest photographs (bottom) between community gardens (C) and market gardens (M) compared separately by date. Significant differences at $p < 0.05$ are indicated by (*).
Figure 10: Mean (± SE) of 2011 reported end-of-season harvest of tomato fruit by garden type. Significant differences between community gardens (C) and market gardens (M) at p < 0.05 are indicated by (*).
Figure 11: Mean (± SE) of 2012 Celebrity plant height by garden type for all plants combined (top) and for each date (bottom). Significant differences between community gardens (C) and market gardens (M) in each comparison at $p < 0.05$ are indicated by (*).
Figure 12: Mean (± SE) of 2012 Celebrity plant surface area by garden type for all plants combined (top) and for each date (bottom). Significant differences between community gardens (C) and market gardens (M) in each comparison at p < 0.05 are indicated by (*).
Figure 13: Mean (± SE) of 2012 Celebrity leaf surface area by garden type for all plants combined (top) and for each date (bottom). Significant differences between community gardens (C) and market gardens (M) in each comparison at p < 0.05 are indicated by (*)
Figure 14: Mean (± SE) of 2012 Celebrity leaf dry weight ratio by garden type for all plants combined (top) and for each date (bottom). Significant differences between community gardens (C) and market gardens (M) in each comparison at p < 0.05 are indicated by (*).
Figure 15: Mean (± SE) of 2012 Celebrity tomato fruit yield by garden type for all dates combined (top) and for each date (bottom). Significant differences between community gardens (C) and market gardens (M) in each comparison at p < 0.05 are indicated by (*).
Figure 16: Mean (± SE) of percent soil moisture and percent soil organic matter by production system and year. Significant differences in each year at p < 0.05 are indicated by (*).
Figure 17: Mean (± SE) of soil texture by production system. Significant differences at $p < 0.05$ are indicated by (*).
Figure 18: Mean (± SE) of soil nitrogen pools and microbial biomass N by production system and year. Significant differences in each year at p < 0.05 are indicated by (*).
Figure 19: Mean (± SE) of soil nematode abundance by trophic group, production system and year. Significant differences in each year at p < 0.05 are indicated by (*).
Figure 20: Indices (mean ± SE) for nematode community by production system and year. Significant differences in each year at p < 0.05 are indicated by (*).
Figure 21: More indices (mean ± SE) for nematode community by production system and year. Significant differences in each year at $p < 0.05$ are indicated by (*).
Figure 22: Estimated mean (± SE) of 2011 abundance of tomato fruit as calculated by number of tomatoes counted in pre-harvest photographs (top), and conversion to estimated weight calculated from number of tomatoes in pre-harvest photographs (bottom) between production systems compared separately by date. Significant differences at p < 0.05 are indicated by (*).
Figure 23: Mean (± SE) of 2011 reported end-of-season harvest of tomato fruit by production system. Significant differences at p < 0.05 are indicated by (*).
**Figure 24**: Mean (± SE) of 2012 Celebrity plant height by production system for all plants combined (top) and for each date (bottom). Significant differences at p < 0.05 are indicated by (*).
Figure 25: Mean (± SE) of 2012 Celebrity plant surface area by production system for all plants combined (top) and for each date (bottom). Significant differences at p < 0.05 are indicated by (*).
Figure 26: Mean (± SE) of 2012 Celebrity leaf surface area by production system for all plants combined (top) and for each date (bottom). Significant differences at $p < 0.05$ are indicated by (*).
Figure 27: Mean (± SE) of 2012 Celebrity leaf dry weight ratio by production system for all plants combined (top) and for each date (bottom). Significant differences at $p < 0.05$ are indicated by (*).
Figure 28: Mean (± SE) of 2012 Celebrity tomato fruit yield by production system for all dates combined (top) and for each date (bottom). Significant differences at p < 0.05 are indicated by (*).
<table>
<thead>
<tr>
<th>Parameter</th>
<th>Data Compared</th>
<th>All Gardens</th>
<th>Gardens with Flat Beds</th>
<th>Gardens with Raised Beds</th>
</tr>
</thead>
<tbody>
<tr>
<td>Moisture Content (%)</td>
<td>2011</td>
<td>0.295; 0.407</td>
<td>0.128; 0.872</td>
<td>0.046; 0.931</td>
</tr>
<tr>
<td></td>
<td>2012</td>
<td>0.583; 0.077</td>
<td>0.155; 0.845</td>
<td>0.549; 0.259</td>
</tr>
<tr>
<td>SOM (%)</td>
<td>2011</td>
<td>0.647; 0.043 *</td>
<td>0.370; 0.630</td>
<td>0.534; 0.275</td>
</tr>
<tr>
<td></td>
<td>2012</td>
<td>0.382; 0.277</td>
<td>0.382; 0.618</td>
<td>-0.354; 0.492</td>
</tr>
<tr>
<td>NH4-N</td>
<td>2011</td>
<td>0.284; 0.426</td>
<td>-0.120; 0.880</td>
<td>-0.012; 0.981</td>
</tr>
<tr>
<td></td>
<td>2012</td>
<td>0.406; 0.244</td>
<td>-0.345; 0.655</td>
<td>0.453; 0.367</td>
</tr>
<tr>
<td>NO3-N</td>
<td>2011</td>
<td>0.642; 0.045 *</td>
<td>0.782; 0.218</td>
<td>0.344; 0.505</td>
</tr>
<tr>
<td></td>
<td>2012</td>
<td>0.547; 0.102</td>
<td>0.950; 0.050 *</td>
<td>0.217; 0.680</td>
</tr>
<tr>
<td>DON</td>
<td>2011</td>
<td>0.423; 0.223</td>
<td>0.019; 0.981</td>
<td>0.285; 0.584</td>
</tr>
<tr>
<td></td>
<td>2012</td>
<td>0.486; 0.155</td>
<td>0.751; 0.249</td>
<td>0.343; 0.505</td>
</tr>
<tr>
<td>MBN</td>
<td>2011</td>
<td>0.412; 0.236</td>
<td>0.122; 0.878</td>
<td>0.161; 0.775</td>
</tr>
<tr>
<td></td>
<td>2012</td>
<td>0.821; 0.004 *</td>
<td>0.990; 0.010 *</td>
<td>0.689; 0.130</td>
</tr>
</tbody>
</table>

**Table 2:** Correlation analysis between the year each garden was established compared to both years of soil parameter data to determine if age correlated with soil health. Correlations were run for the age of all gardens combined, only gardens with a flat bed production system, and only gardens with a raised bed production system. Values are Pearson coefficient; p-value. Significant differences at p < 0.05 are indicated by (*).
<table>
<thead>
<tr>
<th>Parameter</th>
<th>2011</th>
<th>2012</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Reported Yield</td>
<td>Height</td>
</tr>
<tr>
<td>Moisture Content (%)</td>
<td>0.055; 0.880</td>
<td>0.414; 0.235</td>
</tr>
<tr>
<td>SOM (%)</td>
<td>-0.438; 0.206</td>
<td>0.480; 0.161</td>
</tr>
<tr>
<td>NH4-N</td>
<td>-0.841; 0.002</td>
<td>0.068; 0.853</td>
</tr>
<tr>
<td>NO3-N</td>
<td>-0.601; 0.066</td>
<td>-0.169; 0.640</td>
</tr>
<tr>
<td>DON</td>
<td>-0.649; 0.042</td>
<td>-0.013; 0.972</td>
</tr>
<tr>
<td>MBN</td>
<td>0.268; 0.454</td>
<td>-0.183; 0.612</td>
</tr>
<tr>
<td>Bacterivores</td>
<td>-0.665; 0.036</td>
<td>0.026; 0.944</td>
</tr>
<tr>
<td>Fungal Feeders</td>
<td>0.304; 0.393</td>
<td>-0.303; 0.394</td>
</tr>
<tr>
<td>Omnivores</td>
<td>-0.254; 0.478</td>
<td>-0.167; 0.644</td>
</tr>
<tr>
<td>Predators</td>
<td>0.016; 0.965</td>
<td>-0.193; 0.593</td>
</tr>
<tr>
<td>Plant Parasitic</td>
<td>-0.564; 0.089</td>
<td>-0.090; 0.806</td>
</tr>
<tr>
<td>Sample Total</td>
<td>-0.773; 0.009</td>
<td>0.003; 0.994</td>
</tr>
<tr>
<td>Total Genera</td>
<td>-0.192; 0.595</td>
<td>-0.266; 0.457</td>
</tr>
<tr>
<td>MI</td>
<td>0.048; 0.895</td>
<td>-0.772; 0.009</td>
</tr>
<tr>
<td>PPI</td>
<td>0.173; 0.634</td>
<td>-0.383; 0.275</td>
</tr>
<tr>
<td>Combined MI</td>
<td>0.104; 0.775</td>
<td>-0.859; 0.001</td>
</tr>
<tr>
<td>EI</td>
<td>0.152; 0.674</td>
<td>0.586; 0.075</td>
</tr>
<tr>
<td>SI</td>
<td>-0.011; 0.976</td>
<td>-0.356; 0.312</td>
</tr>
<tr>
<td>CI</td>
<td>0.577; 0.081</td>
<td>-0.759; 0.011</td>
</tr>
</tbody>
</table>

**Table 3:** Correlation analysis between the crop data in each year compared to soil and nematode parameters to determine if crop growth and yield correlated with soil health. Values are Pearson coefficient; p-value. Significant differences at p < 0.05 are indicated by (*).
<table>
<thead>
<tr>
<th>Variety</th>
<th>Weight per Fruit (kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Beef Steak</td>
<td>0.48</td>
</tr>
<tr>
<td>Better Boy</td>
<td>0.45</td>
</tr>
<tr>
<td>Big Beef</td>
<td>0.31</td>
</tr>
<tr>
<td>Black Cherry</td>
<td>0.03</td>
</tr>
<tr>
<td>Caspian Pink</td>
<td>0.31</td>
</tr>
<tr>
<td>Cherokee Purple</td>
<td>0.37</td>
</tr>
<tr>
<td>Early Girl</td>
<td>0.17</td>
</tr>
<tr>
<td>Gold Medal</td>
<td>0.57</td>
</tr>
<tr>
<td>Green Zebra</td>
<td>0.09</td>
</tr>
<tr>
<td>Juliet Hybrid</td>
<td>0.03</td>
</tr>
<tr>
<td>Long Keeper</td>
<td>0.17</td>
</tr>
<tr>
<td>Mountain Magic</td>
<td>0.07</td>
</tr>
<tr>
<td>Opalka</td>
<td>0.21</td>
</tr>
<tr>
<td>Red Pear</td>
<td>0.11</td>
</tr>
<tr>
<td>Roma</td>
<td>0.06</td>
</tr>
<tr>
<td>Rose</td>
<td>0.68</td>
</tr>
<tr>
<td>Rutgers Tomato</td>
<td>0.14</td>
</tr>
<tr>
<td>San Marzano</td>
<td>0.11</td>
</tr>
<tr>
<td>Sarah Black</td>
<td>0.28</td>
</tr>
<tr>
<td>Sherril Paste</td>
<td>0.31</td>
</tr>
<tr>
<td>Sun Gold</td>
<td>0.03</td>
</tr>
<tr>
<td>Supersonic</td>
<td>0.26</td>
</tr>
<tr>
<td>Ukranian</td>
<td>0.17</td>
</tr>
<tr>
<td>Valencia</td>
<td>0.26</td>
</tr>
<tr>
<td>Wapsipinicon Peach</td>
<td>0.06</td>
</tr>
</tbody>
</table>

**Table 4:** Tomato varieties and average weight of each variety reported in 2011 being grown by gardeners across all of the urban gardens. These values were used to determine the calculated conversion factor for converting the number of tomatoes in the pre-harvest estimation counts to pre-harvest estimated weights.
Table 5: Total number of Celebrity tomato fruit harvested, % marketable tomato fruit, and % damaged tomatoes by different causes in 2012. Cracking was the designation for a physical break in the top of the fruit during growth. Mold damage was the result of mold rot. Insect damage involved larvae burrowing into the fruit. Herbivory was the category for any large bite taken out of a fruit that was then left behind.
Figure 29: Cumulative rainfall (top), and maximum, minimum, and average temperature (middle and bottom) during each day of the 2011 and 2012 growing seasons.
References


Bassett, T. J. (1979). *Vacant lot cultivation: Community gardening in america, 1893-1978.* Unpublished Master's, University of California, Berkeley,


