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Quantifying soil health and tomato crop productivity in urban community and market gardens

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Abstract Food production in cities offers a framework for local self-reliance and resilience. However, there are concerns about urban soil quality and a general lack of data on productivity in urban gardens. This study investigated soil health via a comprehensive nematode food web analysis and crop productivity via tomato fruit yield in community and market gardens in Cleveland, Ohio, USA over a two-year period. Results revealed that market gardens had significantly higher soil organic matter (SOM) and NH_4-N than community gardens in 2011. While there was no difference between market gardens and community gardens in terms of nematode abundances (except bacteria-feeding nematodes in 2011), market gardens had higher nematode combined maturity index than community gardens in 2011. However, plant-parasitic index was lower in market gardens than in community gardens in 2011. There was no difference in tomato fruit yield in either year between the garden types, but tomato growth responses including leaf dry weight ratio, and plant surface area differed between market and community gardens in 2012. Different weather and related soil and growing conditions likely contributed to the large variation observed between 2011 and 2012; still, soils in market gardens tended to support greater growth and yield than community gardens. Regardless, there was no direct evidence that the gardens were nutrient limited, thereby minimizing the potential for nutrient limitations to contribute to yield differences. Overall, fruit yield ranged from 1.47 to 15.72 kg/m^2, which is consistent with U.S. national average for commercial production systems.

Keywords Urban Agriculture · Urban soil · Soil nematode food web · Nematode biodiversity · Soil quality · Soil organic matter · Nitrogen pools · Garden productivity

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Introduction

Urban agriculture offers a framework for local self-reliance and resilience in cities. Interest in urban agriculture has reemerged worldwide due to the increased need to provide access to healthy food particularly in disadvantaged neighborhoods. Urban agriculture in the form of community gardens has long been shown to allow citizens to become self-reliant in fresh produce (Patel 1991), provide access to healthy food items (Blaine et al. 2010), improve dietary intake of fresh produce (Blaine et al. 2010), increase personal wellness (Brown and Jameton 2000), and promote community cohesion and reduce crime (Patel 1991; Malakoff 1995). Grewal and Grewal (2012) reported that post-industrial cities such as Cleveland have the necessary space including vacant land and flat rooftops to entirely meet their demand for fresh produce, poultry, shell eggs, and honey. Such levels of local self-reliance in food can not only enhance urban food security but can also prevent hundreds of millions of dollars in annual leakage from local economies, leading to enhanced socio-economic resilience of communities (Grewal and Grewal 2012).

Garden-based food production, in both urban and rural locations, has a long and important history in the United States. Gardening has been reported as instrumental in combating increasing food prices, food shortages, and general economic hardship consistently for more than a century (Schupp and Sharp 2011; Tucker 1993). Major national events have also illustrated the value and need for personal food production. One such example is the 'Victory Garden' campaign which mobilized approximately 1.5 million students and 20 million families to grow food on over 60,000 acres of land (mostly in urban settings) during World War II (Census Bureau 2010; Miller 2003; Trelstad 1997). More recently, as personal food production has become less connected to wartime rationing, it has become more connected with other personal and social concerns including the ability to reduce urban blight, enhance physical activity, increase community attachment, and reconnect urban residents of all ages with nature and natural processes (Blaine et al. 2010; Patel 1996; Schukoske 1999; Trelstad 1997; Tucker 1993). The ability of gardening to efficiently supplement or replace other food supplies, especially for the economically disadvantaged, has remained clear (Butterfield 2009). Despite the significant benefits of gardening and the great amount of materials, human labor and financial capital devoted to it in modern times, urban food production in community and market gardens has received relatively little scientific attention. Much is expected of urban gardens but too little is known about them. Local and regional governments, organizations and entrepreneurs are turning to urban food production to repurpose large tracts of foreclosed land (Accordino and Johnson 2000), increase the availability of nutritious fresh produce (Masi 2008; Ogden and Carroll 2010; ver Ploeg et al. 2009) and build local food economies (Grewal and Grewal 2012). Can urban community and market gardens, especially as they may rely on spare native or expensive 'built' soil, be a foundational component in city plans designed to meet these objectives?

A majority of food is grown in rural areas where economies of scale allow few farmers to feed many consumers (most of whom are urban dwellers), and a majority of research is focused on further enhancing the efficiency of this approach (Becker 1984; Tice 1984). Generally abundant and high quality soils, more highly capitalized operations, and profit as a clear production motive are cornerstones of the agroecosystems which dominate the marketplace and national footprint. Urban food production, with community and market gardens, has a different structure-function relationship. For example, small land parcels, surrounding infrastructure, a challenging regulatory and land-ownership environment, and the potential ubiquity of certain contaminants or production disruptions are obstacles to the success of many urban gardeners.

Urban soil itself is also considered by some to be a liability. It is generally regarded as highly disturbed where mixed layers limit nutrient availability and break the rhizosphere where microbes interact with plant roots (Craul 1985; De Kimpe and Morel 2000; Pouyat et al. 2010). Urban soils can also be highly compacted, creating numerous additional problems by reducing pore space (Breland and Hansen 1996; Jim 1998). Abundant pavement that covers and surrounds urban soils absorbs heat, creating microclimates with less rainfall but greater temperatures above optimal for most biological activity (Byrne 2007; Byrne and Grewal 2008; Dixon and Mote 2003; Wilby 2003). However, resiliency and innovation have led to the emergence of two major types of urban gardens which are the subject of this research.

Community gardens are typically neighborhood areas that have been subdivided into smaller plots so that many families or individuals can produce food for home consumption. Community gardens are often supported by federal or city governments; therefore, plot managers are prohibited from selling what they harvest. As a result, community gardeners have a perspective on their activity which lacks a profit motive. Market gardens, on the other hand, may be profit-oriented. Market gardens tend to be larger, non-subdivided tracts managed as a unit by one gardener or by a group of people who work together under a common business plan. Market gardeners seek to attain a level of productivity and efficiency such that the profit obtained from selling what they harvest sustains the business. Community gardens have existed since the gardening movements of the early 1900s. The abundance of vacant land and relatively recent rise in interest in local food has prompted increases in the number of market gardens.

Regardless of motive, garden-based production may be approached in multiple ways. For example, plots may be established in unaltered ‘flat’ soil or in raised beds varying in height, width, depth, and perimeter material. The use of raised beds offers a number of advantages over production in flat soil. For example, raised beds achieve potentially useful separation between production areas and walkways, growing areas and weeds, growing areas and low-lying and flood-prone areas, and potentially compromised native soil and the crop’s rooting medium. Garden soils may be amended regardless of whether or not they are contained in beds, but the process may be more efficient and its outcomes more certain when raised beds are used. Still, raised beds require effort and other resources to install and maintain and they are not required to achieve high yields.

Soil organic matter (SOM) is widely known as a factor affecting the measured health and agriculturally-oriented productivity of soil (Bot and Benites 2005). It is generally accepted that higher levels of SOM are more beneficial, so much attention has been directed to maintaining or increasing SOM in garden and farm soils. SOM may be particularly important to gardeners who lack resources for, or interest in, fertilizer use (Ferris et al. 2001). SOM decomposition can also release plant-available nitrogen (N), the nutrient widely thought to limit crop growth more than any other (Sinclair and Horie 1989). As such, the decomposition of SOM and release of N are a type of “ecosystem service” that allows people to benefit from the environment, its organisms, and their interactions. Processes offering these services may function best in ecosystems closest to a natural, undisturbed state. Ironically, enhancing these processes may be critical in urban settings where disturbance is the norm.

Nematodes have long been known to react predictably to soil conditions, and are now firmly established as indicator species for environmental disturbance (Ferris et al. 2001; Neher 2001; Briar et al. 2007). Measures of the nematode community allow tracking of soil-based processes and the ecosystem services they may provide as nematodes occur at multiple trophic levels, are easily identified under a microscope, and have a clear relationship between oral morphology and feeding habits allowing for easy classification into their trophic groups (Bongers and Bongers 1998; Briar et al. 2007; Neher 2001). They also exist on a gradient from “colonizers,” which are abundant in disturbed soils, to “persisters,” which are more abundant in low stress and stable environments (Bongers 1990). Combining knowledge of nematode feeding habits along with environmental stress tolerances provides insight into the soil environment and make-up of the soil community found in that environment. However, measuring soil health alone does not guarantee an accurate assessment of crop productivity attained in urban gardens.

Quantifying food production is best done through direct measures of yield (count or mass per unit area). Moreover, the use of a common garden crop, such as tomato (Gao et al. 2010), facilitates comparisons of production capacity across experimental units. Tomatoes are easily grown in small spaces and containers and may produce 3 to 5 kg of fruit per plant (Amundson et al. 2012; Gao et al. 2010).

In this study we set out to document the yield and soil health in urban gardens as a function of their type, history and management. Our objective was to identify relationships among chemical, physical and biological characteristics of the soil and nematode communities and tomato plant and fruit variables, as measured over two years in community and market gardens.

Materials and methods

Ten urban garden sites were identified with the help of Ohio State University Extension Service in Cleveland, Ohio in the summer of 2011. An attempt was made to locate gardens as similar in size as possible. The community gardens are located in four corners of Cleveland, with at least one market garden located in a similarly close location. All gardens were classified as established on urban soil—non-agricultural soil in city areas that has been affected through anthropological processes (Bockheim 1974). The age, size, type (community or market), preparation (raised beds or not), and soil pH, % sand, % silt and % clay are given in Table 1. Nine plot sections were randomly selected for soil sampling in each garden site. A total of nine soil cores 2 cm in diameter and up to 10 cm in depth were taken from each plot section and composited

Table 1 List of gardens included in the study and related information including year established, garden size, garden type, presence or absence of raised beds, soil pH, and % sand, silt and clay

Garden	Year Est	Size (ha)	Garden Type	pH	Sand (%)	Silt (%)	Clay (%)	Raised beds
1	1906	2.02	Community	7.01	13.03	6.70	80.27	−
2	1944	0.85	Community	7.06	16.18	6.35	77.47	+
3	1935	0.59	Community	6.98	18.12	5.51	76.37	−
4	1968	0.81	Community	7.14	26.12	7.58	66.30	−
5	2009	0.20	Market	6.67	17.84	30.38	51.78	+
6	2007	0.12	Market	7.31	11.82	29.95	58.22	+
7	2010	1.62	Market	7.18	16.72	13.52	69.77	+
8	2010	0.45	Market	7.46	21.26	10.13	68.61	−
9	2010	0.40	Market	7.42	29.36	13.24	57.41	+
10	1996	0.28	Market	7.23	10.86	19.04	70.10	+

into a single sample per section, for a total of nine samples per garden site. Samples were stored at 4 °C to preserve nematode populations and biochemical reactions for analysis (Barker et al. 1969).

Soil physical, chemical and biological characteristics

Soil organic matter was measured by calculating the sample's weight loss during ignition (Storer 1984). Soil texture was determined according to a modified pipette and sieving technique to separate soil particles into their relative proportions of sand, silt and clay (Gee and Bauder 1986; Mccartney et al. 1997). Soil pH was analyzed using a combination glass electrode in a 1:1 soil and deionized water solution. Soil ammonium (NH_4-N), nitrate (NO_3-N), and dissolved organic nitrogen (DON) were extracted with 0.5 M K_2SO_4 solution followed by digestion by alkaline persulfate oxidation (Cabrera 1993) and analyzed using the indophenol blue technique (Sims et al. 1995). Soil microbial biomass nitrogen (MBN) was determined by chloroform fumigation extraction of soil (Brookes et al. 1985) assuming an extraction efficiency of 0.45 for MBN (Jenkinson 1988), before being treated as the DON.

Nematodes were isolated from soil samples using the Baermann funnel technique (Flegg and Hooper 1970). Ten g of soil was suspended in water for 72 h before collecting the nematodes that had migrated into the bottom 30 ml of suspension. Nematodes were settled overnight at 4 °C before the supernatant was removed and discarded. A volume of boiling water equal to the remaining suspension was added to kill the nematodes by raising the liquid temperature instantly to 50 °C. The first 100 viewed nematodes were counted and identified to genus level under an inverted microscope using morphological characteristics and published keys (Goodey and Goodey 1963; Mai 1975). Each genus was assigned to one of the five trophic groups: plant parasites, fungivores, bacterivores, omnivores and predators according to Yeates et al. (1993). The total number of nematodes was also counted in each sample. Identified nematodes were then also classified along the colonizer-persister (c-p) continuum from 1 to 5 following Bongers (1990). Nematode food web indices, including the structure index, enrichment index, channel index, maturity index and combined maturity index, were calculated from these c-p values and trophic levels following Bongers (1990) and Ferris et al. (2001).

Tomato productivity analysis

Multiple tomato varieties were planted by gardeners' choice in 2011, which is a standard practice in urban gardening. The most common varieties planted were Early Girl, Big Beef, Mountain Magic, Green Zebra, Supersonic and Valencia. Also in 2011, the gardeners self-reported their harvest of all varieties of tomatoes grown within the garden as weight of tomatoes harvested by date. This self-reported yield was converted to kg/sq. meter area for comparison between gardens. During the 2012 growing season, a single (determinate) variety, Celebrity, was provided to gardeners for planting. Seedlings were sown in early May and grown for 3 weeks in organic seed starter, then transplanted into the gardens during the first week of June. Plant growth data were collected from June 19th to August 2nd. Plant height measurements were recorded weekly. Plant surface area was measured by placing a 1 m×1 m frame around the plant and collecting and analyzing a digital image of the frame and plant material within it using WinCam™ software as described previously (Bumgarner et al. 2012). Leaf surface area of the fifth leaf from the apex of the plant was similarly determined using a 15.25 cm frame. Leaf dry weight of the fifth leaf was calculated from a ratio of dry weight/fresh weight. Fruits that reached stage 4, the pink stage, of ripening were harvested weekly, with count and weight of each fruit recorded.

Statistical analysis

ANOVA, considering garden type (community and market gardens) as the factor, and garden age and garden preparation (raised bed, or not) as covariates, was performed on all measured parameters using MINITAB v. 15 (Minitab, Inc., State College, PA, USA). Comparison between years was not made due to extreme differences in weather and differences in studied tomato varieties in each year making the dataset too different for comparison. Pearson's correlations between the age of gardens and soil characteristics and tomato productivity were also determined using MINITAB v. 15 (Minitab, Inc., State College, PA, USA). All data were checked for normality with the Ryan-Joiner test and transformed as needed prior to ANOVA. Means and standard errors were calculated in Excel. Mean separation was determined by Tukey's test, and

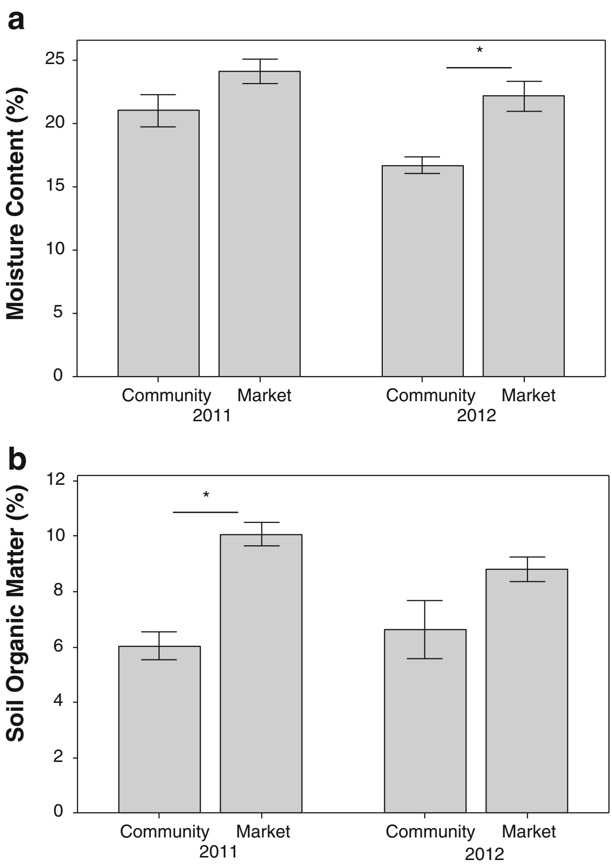


Fig. 1 Mean (± SE) percent soil moisture and soil organic matter by garden type (community and market) and year. Significant differences in each year at $p<0.05$ are indicated by (*)

means that differed at $P<0.05$ were considered significantly different. All graphs represent untransformed data.

Results

Soil physical, chemical and biological characteristics

There was large variation in sand (6 to 30 %), silt (52 to 80 %) and clay (11 to 30 %) contents, as well as pH (6.7 to 7.5) among the gardens (Table 1), but no significant differences in any of the parameters were found between the urban gardens by garden type (community vs. market). Soil moisture was significantly higher in the market than the community gardens in 2012 ($P=0.001$) (Fig. 1a). Soil organic matter ($P=0.015$, Fig. 1b) and NH_4-N ($P=0.002$, Fig. 2a) were significantly higher in the market than the community gardens in 2011.

In 2011, a total of 33 nematode genera representing all five trophic groups in all five c-p classes were identified (Table 2). There were no differences between the market and community gardens in the abundance of nematodes in any of the trophic groups in 2011, except bacteria-feeding nematodes ($P=0.012$) (Fig. 3a). In 2012, 29 nematode genera representing all trophic groups and all five c-p classes were identified (Table 2). Again, there were no differences between the market and community gardens in the abundance of nematodes in any of the trophic groups or c-p classes in 2012.

Nematode food web combined maturity index ($P=0.028$) was higher in market gardens than in community gardens, while plant-parasitic index ($P=0.007$) was lower in market gardens than in community gardens in 2011 (Figs. 4d, c and 5), but not in 2012. Nematode

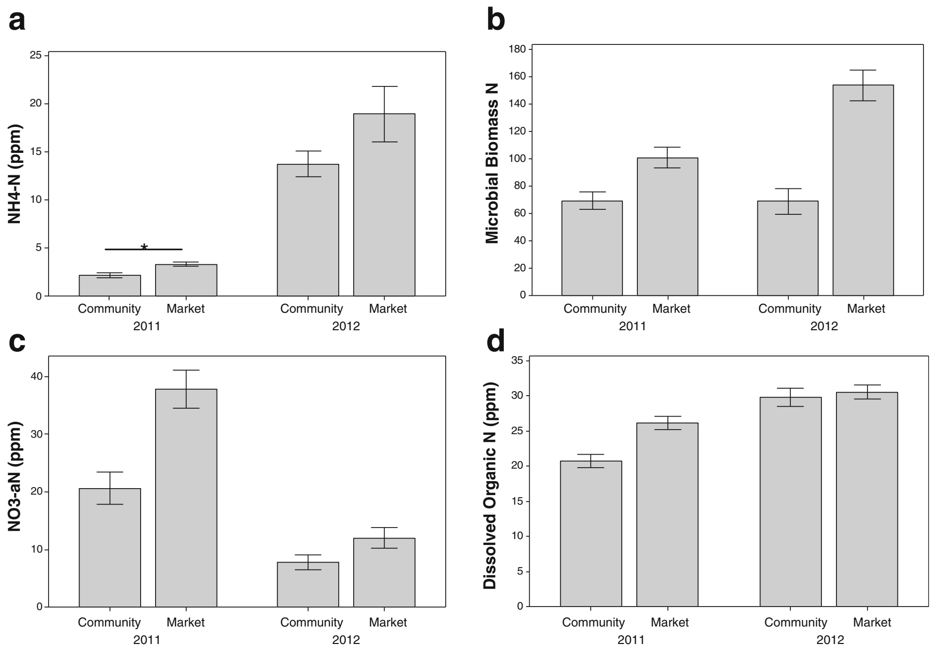


Fig. 2 Mean (± SE) of soil nitrogen pools and microbial biomass N by garden type (community and market) and year. Significant differences between gardens in each year at $p<0.05$ are indicated by (*)

Table 2 Mean (± SE) of nematode genera identified in the urban gardens in each year by trophic group with assigned colonizer-persister scale values in parenthesis (according to Bongers 1990). '-' indicates not found that year. Genera with means of 0.00 were present in lower numbers than represented by the number of figures shown

Trophic group	Nematode genus	2011	2012
Bacterivores	*Diplogaster (1)*	2.53±0.64	0.56±0.24
	Diplogasteroides (1)	0.53±0.24	0.06±0.04
	Mesorhabditis (1)	–	0.00±0.00
	Monhystera (1)	1.56±0.57	0.00±0.00
	Panagrolaimus (1)	7.58±1.11	2.44±0.57
	Pelodera (1)	1.14±0.52	–
	Rhabditis (1)	9.61±2.68	3.33±0.67
	Acrobeles (2)	0.08±0.08	3.06±0.94
	Acrobeloides (2)	5.72±0.87	1.61±0.41
	Cephalobus (2)	0.36±0.11	0.00±0.00
	Chiloplacus (2)	1.47±0.36	0.00±0.00
	Eucephalobus (2)	3.94±0.89	0.17±0.07
	Plectus (2)	2.36±0.59	0.75±0.25
	Wilsonema (2)	0.75±0.56	–
	Rhabdolaimus (3)	0.36±0.27	0.00±0.00
Plant parasites	*Discotylenchus (1)*	0.50±0.29	–
	Aglenchus (2)	0.47±0.27	0.00±0.00
	Filenchus (2)	5.28±1.14	0.42±0.15
	Malenchus (2)	0.11±0.09	–
	Paratylenchus (2)	0.47±0.29	0.00±0.00
	Tylenchus (2)	6.36±1.28	3.03±1.09
	Belonolaimus (3)	–	0.44±0.21
	Dolichodorus (3)	0.14±0.09	–
	Helicotylenchus (3)	0.08±0.05	–
	Hoplolaimus (3)	0.08±0.05	0.00±0.00
	Pratylenchus (3)	1.22±0.45	–
	Tylenchorhynchus (3)	0.03±0.03	0.00±0.00
Fungivores	*Aphelechoides (2)*	3.44±0.72	1.53±0.73
	Aphlenchus (2)	4.50±1.53	1.97±0.65
Omnivores	*Alaimus (4)*	0.11±0.09	0.00±0.00
	Dorylaimus (4)	0.56±0.27	0.03±0.03
	Eudorylaimus (4)	2.11±0.47	0.03±0.03
	Pungentus (4)	0.28±0.18	0.00±0.00
	Aporcelaimellus (5)	0.00±0.00	0.00±0.00
Predators	*Mononchus (4)*	0.36±0.17	0.00±0.00
	Mylonchus (4)	0.14±0.07	0.03±0.03

enrichment index and structure index were not different between community gardens and market gardens in both years (Fig. 5). The overall nematode faunal profile showed that the soil food webs were generally enriched in all gardens in both 2011 and 2012, but were more structured in 2011 than in 2012 (Fig. 6a and b).

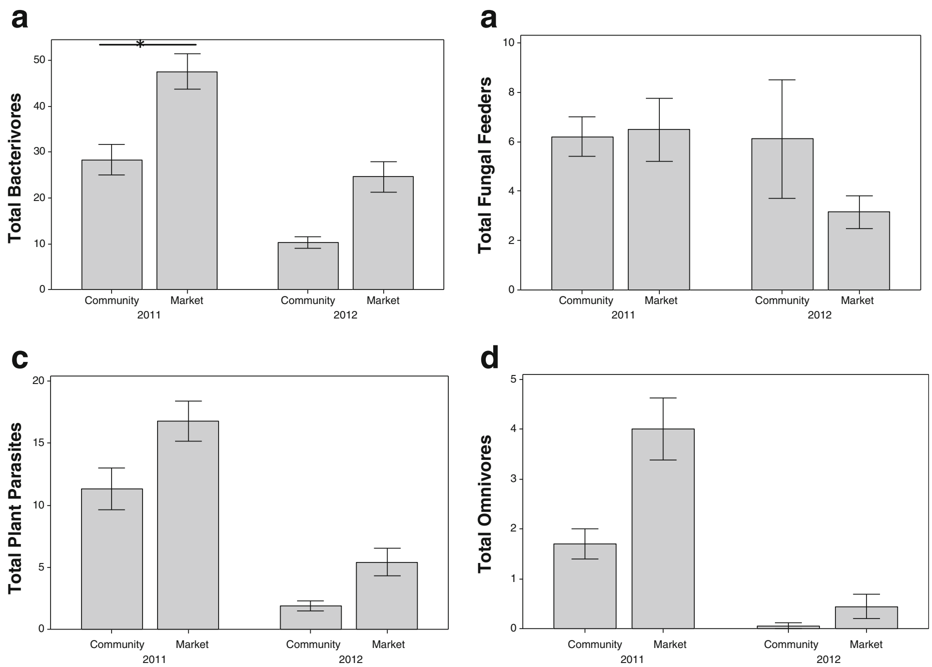


Fig. 3 Mean (± SE) soil nematode abundance by trophic group for garden type (community and market) and year. Significant differences in each year at $p<0.05$ are indicated by (*)

Tomato productivity analysis

The overall tomato fruit yield in 2011 ranged from 0.53 to 7.81 kg/sq. but the mean yield did not significantly differ between the community and market gardens (Fig. 7a). In 2012, the tomato fruit yield ranged from 1.47 to 15.72 kg/sq. m and again the mean yield did not differ between the community and market gardens (Fig. 7a).

In 2012, the leaf dry weight ratio ($P=0.013$), and plant surface area ($P=0.042$) were higher in community gardens than in market gardens (Fig. 7d and e).

Discussion

Market gardens tended to have higher values for indicators of positive soil health than community gardens. We defined soil health according to Knight et al. (2013, in press) as a state of composite well being in terms of biological, chemical, and physical properties of the soil as they relate to crop productivity. Knight et al. (2013, in press) concluded that active soil carbon, plant-parasitic nematodes (PPN), total number of nematodes (TNN), SOM, MBN, clay, and nematode food web enrichment index can serve as important soil health indicators that have potential for predicting crop productivity and quality in urban soils. We therefore focused specifically on SOM, various N pools including NH_4-N, NO_3-N, and MBN, and a range of soil nematode community parameters including PPN, TNN, and enrichment index to determine differences in soil health in urban gardens. Our results reveal differences in these soil health parameters between the market and community gardens, thus supporting their utility as tools for soil health assessment in urban gardens.

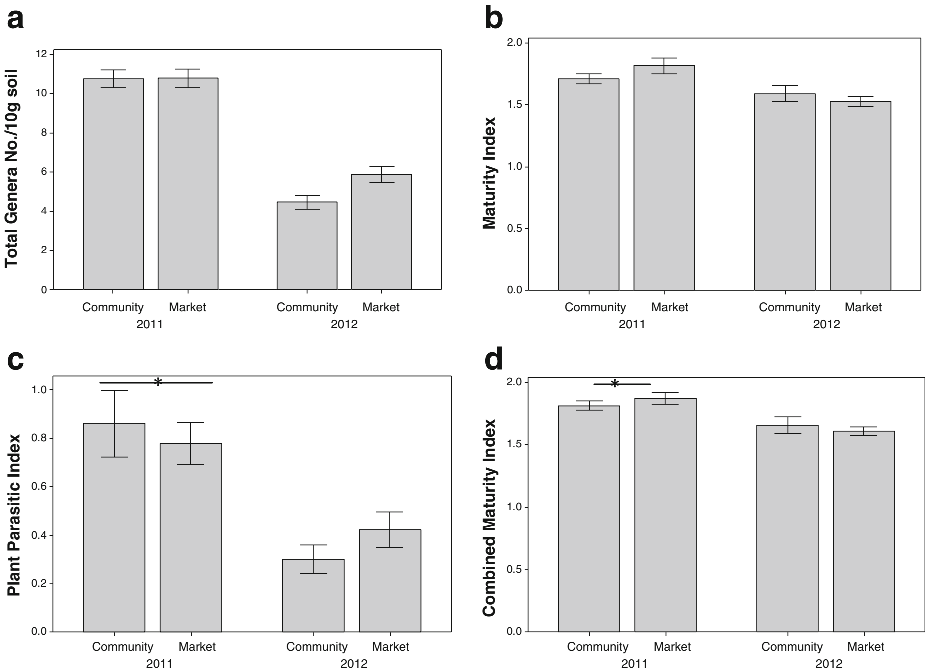


Fig. 4 Mean (± SE) number of nematode genera and soil food web indices by garden type (community and market) and year. Significant differences in each year at $p<0.05$ are indicated by (*)

The nematode enrichment index, structure index and channel index illustrate the soil food web conditions. The high enrichment index values for all gardens indicate a high nutrient content "enriching" the soil food web, while the low structural index values indicate high soil disturbance preventing the development of a well-structured food web. This, along with a low channel index indicating bacterial dominance in the decomposition pathway (Ferris et al. 2001), is to be expected as also seen in our previous research on urban gardens in Akron and Cleveland (Grewal et al. 2011). The soil is often loaded with nutrients via the application of organic amendments and fertilizers during the growing season, and broken or dug into as crops are planted, weeded, and harvested. Enrichment index in both community and market gardens are high, indicating high nutrient availability in both garden types.

The maturity index and combined maturity index, which measure the extent of disturbance in the environment on the soil food web (Bongers 1990; Briar et al. 2007), were low, indicating high environmental disturbances affecting the nematode food web in the community and market gardens. Further, the combined maturity index in 2011 were significantly higher in the market gardens than community gardens, which suggest that the market gardens were undergoing lesser disturbance, leading to the establishment and increase in high cp value nematode trophic groups.

SOM was higher in the market gardens than community gardens, especially in 2011. SOM tends to increase with age in urban soils (Park et al. 2010); therefore, our results were surprising in that we recorded higher SOM levels in recently established gardens, especially market gardens. Still, little correlation between SOM and garden age was observed in this study, suggesting that the observed SOM levels cannot be attributed primarily to aging, erosion, or weathering processes affecting soil status. Most likely, organic amendments were a major source of the measured SOM. Also soil core sampling occurred in June after

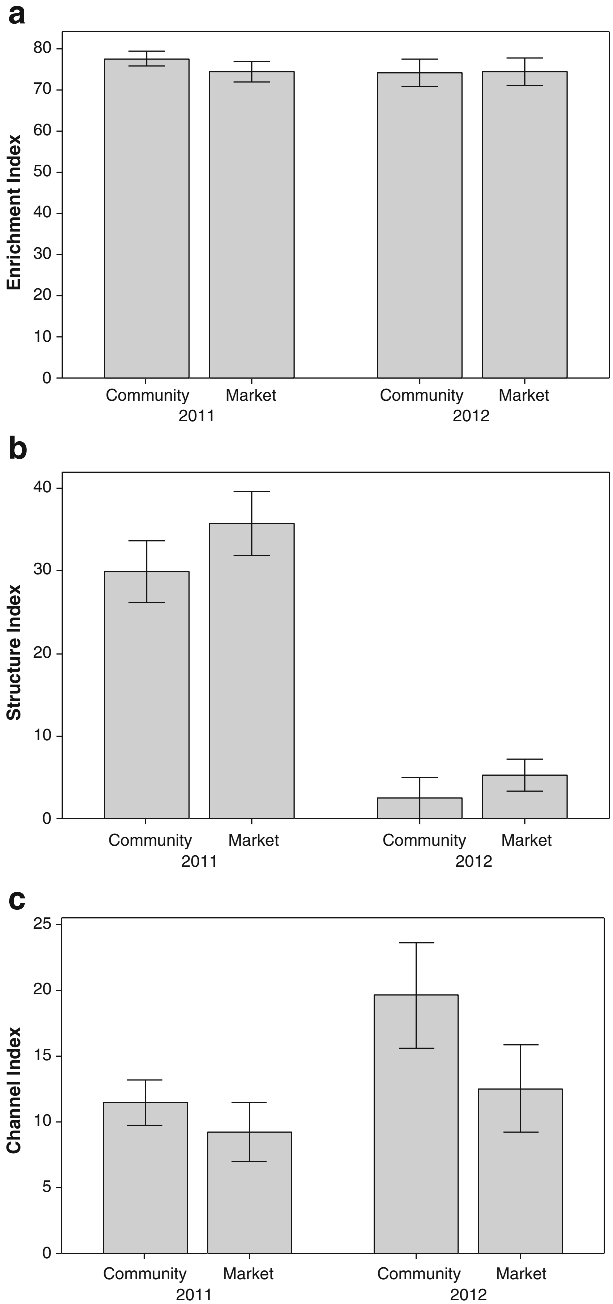


Fig. 5 Mean (± SE) soil nematode food web enrichment, structure and channel index values by garden type (community and market) and year

compost and/or other amendments were applied and incorporated as part of the soil preparation process. N mineralization rate and gardener activity (including soil preparation) are influenced by temperature, rainfall and other factors that differed annually in this study. Therefore, observed SOM levels represent the sum of natural and anthropogenic activity.

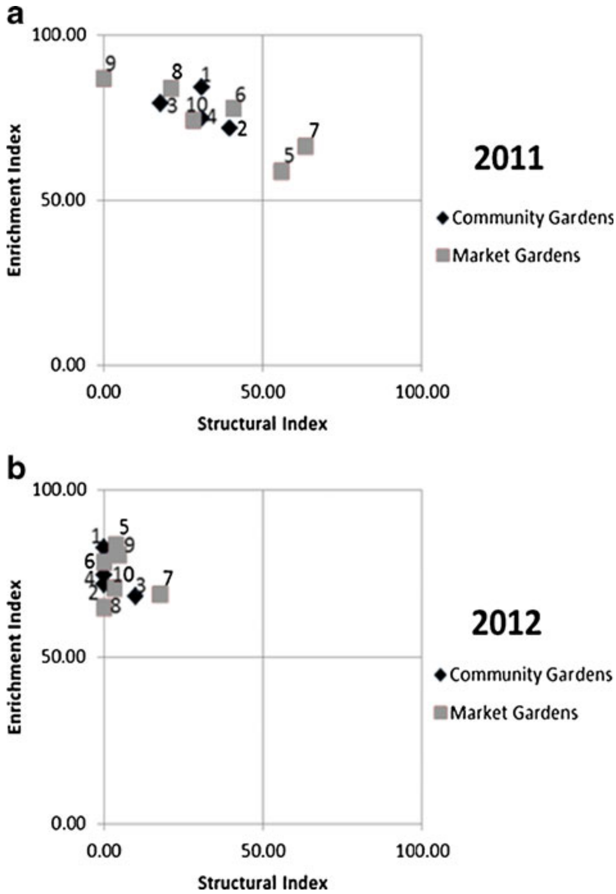


Fig. 6 Faunal profiles of the nematode food web in community gardens and market gardens depicting structure and enrichment indices in 2011 (**a**) and 2012 (**b**). Numbers designate gardens shown in Table 1

Both the soil N pools and nematode community parameters differed between the 2 years of the study and these differences are likely due to the extreme differences in weather conditions between 2011 and 2012 (Fig. 8b, c). In 2011, the spring-time average temperature of 21 °C was accompanied by 51 cm of rainfall by June 1st, the wettest spring on record for Cleveland (Exner 2012a; National Weather Service Forecast Office 2012; OARDC Weather System 2012). In contrast, 2012 was the hottest year on record and only 20 cm of rainfall were recorded between March 20th and July 13th (Fig. 8a) (Exner 2012b; OARDC Weather System 2012). Microbial activity and, therefore, substrate decomposition and mineralization, tend to be most rapid in warm, moist soil (Alon and Steinberger 1999; Cookson et al. 2007; Waldrop and Firestone 2004) and lag phases between soil amendment and N mineralization are well documented (Chae and Tabatabai 1986). Moreover, strong anecdotal evidence suggests that irrigation practices can vary among gardeners, making irrigation an unreliable substitute for adequate rainfall. Therefore, it is reasonable to conclude that mineralization was higher and more rapid in 2011 than 2012.

Differences in the abundance of nematodes could also be traced to differences in weather conditions. The lower nematode abundance in the hot and dry 2012 season could be due to the high sensitivity of nematodes to rainfall in terrestrial environments (McSorley 1997). Or they may be sensitive to how the soil microbial community reacts to rainfall; if the microbial community

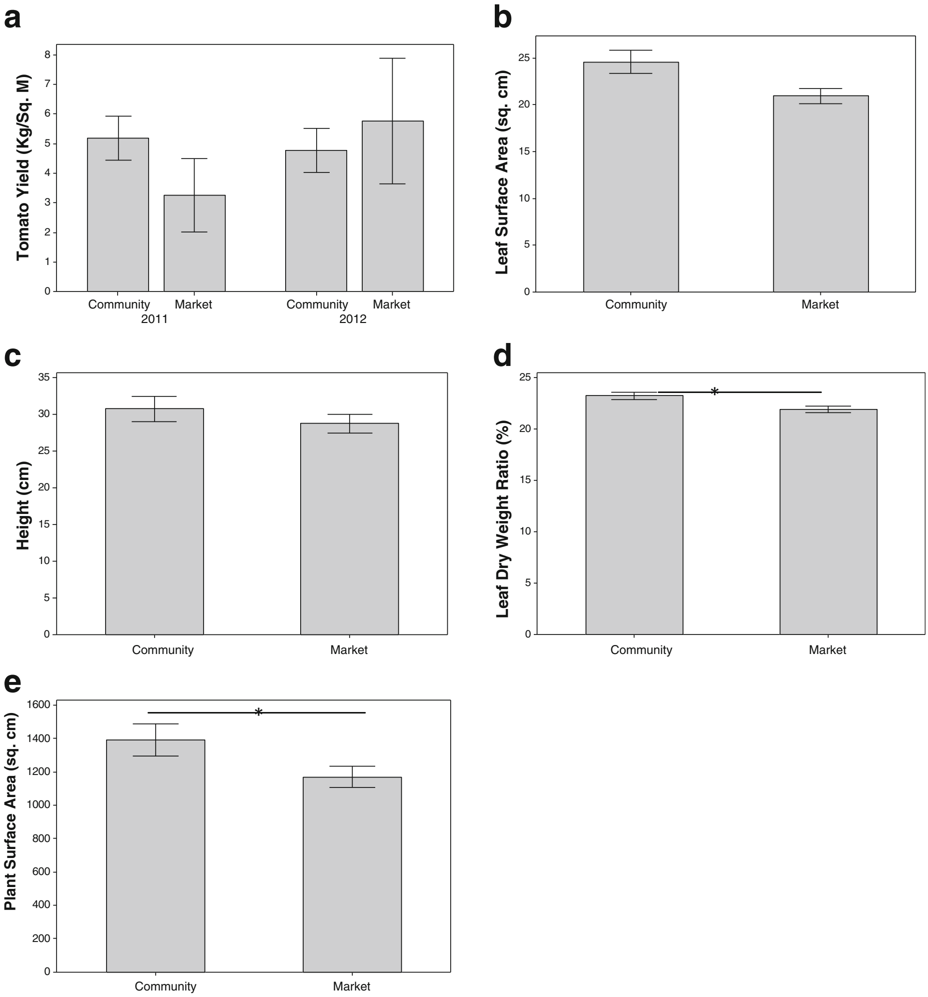
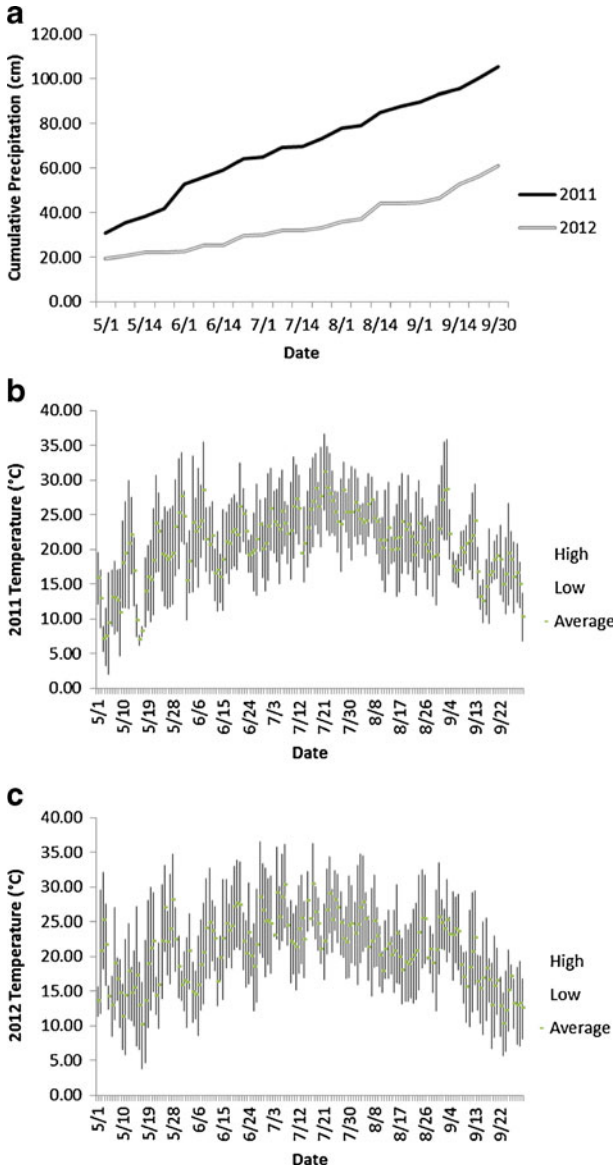


Fig. 7 Mean (± SE) tomato yield in 2011 and 2012 (**a**) and tomato growth parameters by garden type (community or market) in 2012 (**b** through **e**). The 2011 yield data were self-reported by gardeners and constituted a diversity of tomato varieties. The 2012 yield data and all plant growth parameters are based on a single tomato variety (Celebrity) grown in each garden. Significant differences at $p<0.05$ are indicated by (*)

activity is slowed by dry conditions, the nematodes that feed on those microorganisms will also be affected (Birch 1960). Similarly, since there is a communal relationship of plants supplying sugars to soil microorganisms in exchange for nutrients (Hamilton and Douglas 2001), if the weather affected the tomato plants such that the amount of root exudates that could be secreted were reduced, then the soil food web would also be impacted by limiting a major energy source, which would in turn reduce the nematode population by limiting their food source.

N availability often has measurable impacts on plant growth and yield but in a manner mitigated by many other genetic, environmental and procedural factors. Therefore, care must be taken in drawing conclusions from one set of observed, extractable-N and plant growth or fruit yield value set. Still, a long standing body of evidence (e.g., Abdul-Baki et al. 1997; Ganmore-Neumann and Kafkafi 1980; Locascio et al. 1992; Tei et al. 2002) indicates that

Fig. 8 Cumulative rainfall (*top*) and maximum, minimum, and average temperature (*middle* and *bottom*) during each day of the 2011 and 2012 growing seasons



soil N values between 44.6 and 89.3 ppm can be optimal (Doorenbos and Kassam 1979; Hochmuth 1988; Maynard and Hochmuth 1995) in tomato production. In 2011, the market gardens had a combined NH_4-N and NO_3-N concentration of nearly 40 ppm; the combined N concentration in the community gardens was approximately 20 ppm. Interestingly, this difference in plant available N in 2011 was not reflected in self-reported total crop yield between the garden types.

Tomato varieties planted differed among gardens in 2011. As varieties differ in apparent N responses (Kooner and Randhawa 1990), we included Celebrity as the sole variety in all gardens in 2012. The plant available N concentration in June 2012 was approximately

18 ppm in both garden types. Still, characteristic symptoms of severe N stress (Scholberg et al. 2000) were not observed, suggesting that N availability was not limiting. This could be due to the fact that both SOM and MBN contents were high in all types of gardens which could have served as slow-release sources of N better matched with plant growth requirements. This contention is supported by the high enrichment index of the soil nematode food web, which suggests high nutrient content in all gardens.

In 2012, tomato growth responses including leaf dry weight ratio and plant surface area differed between market and community gardens. This difference could be only weakly attributed to total N availability since it did not appear to differ significantly and consistently among garden types. In addition, potential differences in soil moisture availability are a more plausible explanation of the garden-specific tomato growth and fruiting characteristics observed here, regardless of year. Market gardens tended to employ drip irrigation and staff dedicated to daily crop management while both were typically lacking in community gardens. Therefore, while not measured, we expect soil moisture availability to have fluctuated significantly in community gardens. Soil moisture fluctuations are associated with periods of minimal and rapid above-ground growth and fruit development (Gates 1955). This phenomenon can help explain the larger average surface area of plants grown in community gardens.

Under experimental conditions imposed here, abiotic and biotic (especially nematode community) parameters were more sensitive indicators of urban community and market garden and soil history and management than tomato fruit yield. Tomato is a long-season crop with vegetative and reproductive phases. Outcomes of these phases are subject to genetic, environmental and procedural factors. The 2011 study involved multiple varieties grown under conditions that differed significantly from ones that prevailed in 2012. The 2012 season set historical records in temperature (high) and rainfall (low), factors that can influence fruit initiation and development (Bastin and Henken 1997; Johnson and Hall 1953). Still, modern hybrids such as Celebrity are developed to yield well under a range of conditions. Earlier work indicates that short-season non-fruiting crops such as lettuce may be suitable as indicators of potential urban soil health (Knight et al. 2013 in press). Nevertheless, tomato fruit yield of 1.47 to 15.72 kg/m^2 recorded in urban gardens in this study is consistent with U.S. national average for commercial production systems. This underscores the potential of urban food production activities to provide both social and economic resilience in cities, an idea that is gaining momentum.

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References

Abdul-Baki AA, Teasdale JR, Korcak RF (1997) Nitrogen requirements of fresh-market tomatoes on hairy vetch and black polyethylene mulch. HortSci 32(2):217–221

Accordino J, Johnson GT (2000) Addressing the vacant and abandoned property problem. J Urban Aff 22(3):301–315

Alon A, Steinberger Y (1999) Effect of nitrogen amendments on microbial biomass, above-ground biomass and nematode population in the Negev desert soil. J Arid Environ 41(4):429–441

Amundson S, Deyton DE, Kopsell DA, Hitch W, Moore A, Sams CE (2012) Optimizing plant density and production systems to maximize yield of greenhouse-grown 'Trust' Tomatoes. HortTechnology 22(1):44–48
Barker K, Nusbaum C, Nelson L (1969) Effects of storage temperature and extraction procedure on recovery of plant-parasitic nematodes from field soils. J Nematol 1(3):240
Bastin S, Henken K (1997) Water content of fruits and vegetables. http://www.ca.uky.edu/enri/pubs/enri129.pdf. Accessed 20 Nov 2012
Becker R (1984) Vegetable gardening in the United States—a history, 1565–1900. HortSci 19(5):624–629
Birch H (1960) Nitrification in soils after different periods of dryness. Plant Soil 12(1):81–96
Blaine TW, Grewal PS, Dawes A, Snider D (2010) Profiling community gardeners. J Ext 48(6)
Bockheim J (1974) Nature and properties of highly disturbed urban soils. Philadelphia, Pennsylvania. Div.S-5, Soil Science Society of America, Chicago, Illinois
Bongers T (1990) The maturity index: an ecological measure of environmental disturbance based on nematode species composition. Oecologia 83(1):14–19
Bongers T, Bongers M (1998) Functional diversity of nematodes. Appl Soil Ecol 10(3):239–251
Bot A, Benites J (2005) The importance of soil organic matter. FAO Soils Bulletin 80. FAO, Rome
Breland TA, Hansen S (1996) Nitrogen mineralization and microbial biomass as affected by soil compaction. Soil Biol Biochem 28(4–5):655–663
Briar SS, Jagdale GB, Cheng Z, Hoy CW, Miller SA, Grewal PS (2007) Indicative value of soil nematode food web indices and trophic group abundance in differentiating habitats with a gradient of anthropogenic impact. Environ Bioindic 2(3):146–160
Brookes P, Landman A, Pruden G, Jenkinson D (1985) Chloroform fumigation and the release of soil nitrogen: a rapid direct extraction method to measure microbial biomass nitrogen in soil. Soil Biol Biochem 17(6):837–842
Brown KH, Jameton AL (2000) Public health implications of urban agriculture. J Public Health Policy 21:20–39
Bumgarner NR, Miller WS, Kleinhenz MD (2012) Digital image analysis to supplement direct measures of lettuce biomass. HortTechnology 22(4):547–555
Butterfield B (2009) The impact of home and community gardening in America. National Gardening Association, South Burlington
Byrne LB (2007) Habitat structure: a fundamental concept and framework for urban soil ecology. Urban Ecosyst 10(3):255–274
Byrne LB, Grewal PS (2008) Introduction to ecological landscaping: a holistic description and framework to guide the study and management of urban landscape parcels. Cities Environ 1(2):1–20
Cabrera M (1993) Alkaline persulfate oxidation for determining total nitrogen in microbial biomass extracts. Soil Sci Soc Am J 57(4):1007
Census Bureau (2010) State and county quickfacts. http://quickfacts.census.gov/qfd/states/00000.html. Accessed 14 Dec 2010
Chae Y, Tabatabai M (1986) Mineralization of nitrogen in soils amended with organic wastes. J Environ Qual 15(2):193–198
Cookson WR, Osman M, Marschner P, Abaye DA, Clark I, Murphy DV, Stockdale EA, Watson CA (2007) Controls on soil nitrogen cycling and microbial community composition across land use and incubation temperature. Soil Biol Biochem 39(3):744–756
Craul PJ (1985) A description of urban soils and their desired characteristics. J Arboric 11(11):330–339
De Kimpe CR, Morel JL (2000) Urban soil management: a growing concern. Soil Sci 165(1):31
Dixon PG, Mote TL (2003) Patterns and causes of Atlanta's urban heat island—initiated precipitation. J Appl Meteorol 42(9):1273–1284
Doorenbos J, Kassam AH (1979) Yield response to water. FAO irrigation and drainage paper, 33rd edn. FAO, Rome
Exner R (2012a, Monday, July 16, 2012) Cleveland high temperature trend extends back 15 months: Statistical snapshot. The Plain Dealer http://www.cleveland.com/datacentral/index.ssf/2012/07/cleveland_high_temperature_tre.html. Accessed 20 July 2012
Exner R (2012b, Friday, July 13, 2012) Cleveland's spring and early summer has been among the driest on record. The Plain Dealer http://www.cleveland.com/datacentral/index.ssf/2012/07/clevelands_spring_and_early_su.html. Accessed 20 July 2012
Ferris H, Bongers T, De Goede R (2001) A framework for soil food web diagnostics: extension of the nematode faunal analysis concept. Appl Soil Ecol 18(1):13–29
Flegg J, Hooper D (1970) Extraction of free-living stages from soil. Technical Bulletin. Ministry of Agriculture, Fisheries and Food, 5th ed. 2: pp 5–22
Ganmore-Neumann R, Kafkafi U (1980) Root temperature and percentage NO3-/NH4 effect on tomato plant development I. morphology and growth. Agron J 72(5):758–761
Gao G, Bergefurd B, Precheur B (2010) Growing tomatoes in the home garden. No. HYG-1624-10) Fact Sheet: Agriculture and Natural Resources, The Ohio State University Extension Service

Gates C (1955) The response of the young tomato plant to a brief period of water shortage. Aust J Biol Sci 8(2):196–214
Gee G, Bauder W (1986) Principle of the pipet method. Agronomy. Methods of soil analysis. Part I: Physical and mineralogical methods. American Society of Agronomy: Soil Science Society of America, Madison, pp 394–396
Goodey T, Goodey JB (1963) Soil and freshwater nematodes. Methuen; Wiley, London; New York
Grewal SS, Grewal PS (2012) Can cities become self-reliant in food? Cities 29(1):1–11
Grewal SS, Cheng Z, Masih S, Wolboldt M, Huda N, Knight A, Grewal PS (2011) An assessment of soil nematode food webs and nutrient pools in community gardens and vacant lots in two post-industrial American cities. Urban Ecosyst 14(2):181–194
Hamilton EW, Douglas AF (2001) Can plants stimulate soil microbes and their own nutrient supply? Evidence from a grazing tolerant grass. Ecology 82:2397–2402
Hochmuth GJ (1988) Tomato poduction guide for Florida. Florida Cooperative Extension Service, Institute of Food and Agricultural Sciences, University of Florida
Jenkinson D (1988) Determination of microbial biomass carbon and nitrogen in soil. In: Wilson J (ed) Advances in nitrogen cycling in agricultural ecosystems. CAB International, Wallingford, pp 368–386
Jim CY (1998) Physical and chemical properties of a Hong Kong roadside soil in relation to urban tree growth. Urban Ecosyst 2(2/3):171
Johnson S, Hall WC (1953) Vegetative and fruiting responses of tomatoes to high temperature and light intensity. Bot Gaz 114(4):449–460
Knight A, Cheng Z, Grewal SS, Islam KR, Kleinhenz MD, Grewal PS (2013) Soil health as a predictor of lettuce productivity and quality: a case study of urban vacant lots. Urban Ecosyst. doi:10.1007/s11252-013-0288-1
Kooner KS, Randhawa KS (1990) Effect of varying levels and sources of nitrogen on yield and processing qualities of tomato varieties. Acta Horticult 267:93–99
Locascio S, Clark G, Csizinszky A, Stanley C, Olson S, Rhoads F, Smajstrla AG, Vellidis G, Edling RJ, Hanna HY (1992) Water and nutrient requirements for drip-irrigated vegetables in humid regions. South Coop Ser Bull 363:17
Mai WF (1975) Pictorial key to genera of plant-parasitic nematodes. Comstock Pub. Associates, Ithaca
Malakoff D (1995) What good is community greening? American Community Gardening Association Monograph. American Community Gardening Association, Philadelphia, pp 16–20
Masi B (2008) Defining the urban-agrarian space. In: Rugare S, Schwarz T, C. U. D. Collaborative (eds) Cities growing smaller, Cleveland Urban Design Collaborative, College of Architecture and Environmental Design, Kent State University, pp 102
Maynard DN, Hochmuth GJ (1995) Vegetable production guide for Florida. University of Florida, Cooperative Extension Service, Institute of Food and Agricultural Sciences
Mccartney DA, Stinner BR, Bohlen PJ (1997) Organic matter dynamics in maize agroecosystems as affected by earthworm manipulations and fertility source. Soil Biol Biochem 29(3):397–400
McSorley R (1997) Relationship of crop and rainfall to soil nematode community structure in perennial agroecosystems. Appl Soil Ecol 6(2):147–159
Miller C (2003) In the sweat of our brow: citizenship in American domestic practice during WWII-victory gardens. J Am Cult 26(3):395–409
National Weather Service Forecast Office (2012) Cleveland wettest in 141 years. http://www.erh.noaa.gov/cle/wx_events/2011/Precip/new_record_CLE.php. Accessed 13 Oct 2012
Neher DA (2001) Role of nematodes in soil health and their use as indicators. J Nematol 33(4):161–168
Ogden CL, Carroll MD (2010) Prevalence of overweight, obesity, and extreme obesity among adults: United States, trends 1976–1980 through 2007–2008. NCHS Health E-Stat
Park SJ, Cheng Z, Yang H, Morris EE, Sutherland M, McSpadden Gardener BB, Grewal PS (2010) Differences in soil chemical properties with distance to roads and age of development in urban areas. Urban Ecosyst 13(4):1–15
Patel IC (1991) Gardening's socioeconomic impacts. J Ext 29:7–8
Patel IC (1996) Rutgers urban gardening: a case study in urban agriculture. J Agric Food Inf 3(3):35–46
Pouyat RV, Szlavecz K, Yesilonis ID, Groffman PM, Schwarz K (2010) Chemical, physical and biological characteristics of urban soils. In: Aitkenhead-Peterson J, Volder A (eds) Urban ecosystem ecology. American Society of Agronomy, Madison, pp 119–152
Scholberg J, McNeal BL, Boote KJ, Jones JW, Locascio SJ, Olson SM (2000) Nitrogen stress effects on growth and nitrogen accumulation by field-grown tomato. Agron J 92(1):159–167
Schukoske JE (1999) Community development through gardening: state and local policies transforming urban open space. NYUJ Legis Public Policy 3:351

Schupp JL, Sharp JS (2011) Exploring the social bases of home gardening. Agric Hum Values 29(1):1–13
Sims G, Ellsworth T, Mulvaney R (1995) Microscale determination of inorganic nitrogen in water and soil extracts. Commun Soil Sci Plant Anal 26(1–2):303–316
Sinclair TR, Horie T (1989) Leaf nitrogen, photosynthesis, and crop radiation use efficiency: a review. Crop Sci 29(1):90–98
Storer DA (1984) A simple high sample volume ashing procedure for determination of soil organic matter. Commun Soil Sci Plant Anal 15(7):759–772
Tei F, Benincasa P, Guiducci M (2002) Critical nitrogen concentration in processing tomato. Eur J Agron 18(1):45–55
Tice PM (1984) Gardening in America, 1830–1910. Strong Museum, Rochester
Trelstad B (1997) Little machines in their gardens: a history of school gardens in America, 1891 to 1920. Landsc J 16(2):161–173
Tucker DM (1993) Kitchen gardening in America: A history. Iowa State University Press, Ames
ver Ploeg M, Breneman V, Farrigan T, Hamrick K, Hopkins D, Kaufman P, Lin BH, Nord M, Smith T, Williams R, Kinnison K, Olander C, Singh A, Tuckermanty E (2009) Access to affordable and nutritious food measuring and understanding food deserts and their consequences: Report to congress (Report to Congress). Washington, D.C.: U.S. Dept. of Agriculture, Economic Research Service
Waldrop M, Firestone M (2004) Altered utilization patterns of young and old soil C by microorganisms caused by temperature shifts and N additions. Biogeochemistry 67(2):235–248
OARDC Weather System (2012) Daily weather data from 3/1/2011 to 9/25/2012 for Avon station. http://www.oardc.ohio-state.edu/newweather/dailyinfo.asp?id=17. Accessed 13 Oct 2012
Wilby RL (2003) Past and projected trends in London's urban heat island. Weather 58(7):251–260
Yeates GW, Bongers T, De Goede RGM, Freckman DW (1993) Feeding habits in soil nematode families and genera—an outline for soil ecologists. J Nematol 25(3):315