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ORIGINAL RESEARCH ARTICLE

Chemical and biological indicators of soil health in Chicago urban gardens and farms

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Abstract

Urban food production is conducted in highly heterogeneous environments that have undergone considerable manipulation by building, demolition, and/or industrial pollution. This study evaluated soil quality characteristics in urban sites currently used for vegetable production across an urban to peri-urban gradient in Chicago, IL, USA. Twenty-one sites were classified based on the scale of management as private home gardens, community gardens, institutional farms, and private urban farms. We quantified indicators of soil fertility, nematode trophic composition, and indicators of the food web status (Maturity Index, Enrichment Index, Channel Index, and Structure Index). We also quantified concentrations of soil contaminants including lead (Pb), arsenic (As), and zinc (Zn). Analysis of free-living nematode families suggested that communities differ across sites based on their scale of management and are likely influenced by soil organic matter and soil pH. Concentrations of Pb, As, and Zn were below the levels of concern and did not influence nematode community structure. Finally, soil fertility was significantly increased by management, particularly in community gardens and urban farms. Adoption of best management practices in urban agriculture, such as reduced mixing through tillage, and the use of soil testing as a decision-support tool that helps optimize compost application, would reduce potential ecosystem disservices and promote food webs with greater functional diversity.

1 | INTRODUCTION

The importance of urban agricultural (UA) soils in contemporary societies warrants a systematic analysis of the health of these soils and their ability to support healthy and diverse soil communities which ultimately contribute to food production and the success of urban agricultural endeavors. Urban soil systems are unlike their rural counterparts in terms of their physical and chemical properties and management (Wortman & Lovell, 2013). Consequently, the findings from research on the latter cannot necessarily be extended to the former. Urban agricultural soils are highly variable chemically and physically at fine geographic scales (Beniston & Lal, 2012). This diversity reflects the management history of individual sites both before and after their conversion to food production (Egerer, Ossola, & Lin, 2018; Pfeiffer, Silva, & Colquhoun, 2014). Some urban farms and gardens may have been founded on land with a history of industrial or commercial use while others may be located on relatively undisturbed sites in backyards, utility rights-of-way, or parks. Urban agriculturalists may grow crops directly in the ground, in “native” soil, or

Abbreviations: NMDS, non-metric dimensional scaling; UA, urban agriculture they may construct aboveground soil and compost-based systems to obviate the problem of soil contamination (Moskal & Berthrong, 2018; Taylor & Lovell, 2014). These aboveground systems may consist of raised beds containing media of varying depths and composition or cap-and-fill systems of similarly varying configurations and characteristics (Wortman & Lovell, 2013). Soils may be tilled by rotary plow, by hand, or not at all (Moskal & Berthrong, 2018; Taylor & Lovell, 2014) depending on the scale of the operation. As a result of these diverse legacies of management, urban agricultural soils may, at one end of the soil quality spectrum, be highly compacted with low levels of soil organic matter; at the other, they may have low bulk densities and very high levels of soil organic matter—up to seven times that of native soils—because of high inputs of compost or other organic amendments (Moskal & Berthrong, 2018; Pfeiffer et al., 2014; Taylor & Lovell, 2014).

Urban agricultural soils may also be nutrient enriched compared to soils in rural areas. In aboveground urban systems, this may be due to the inclusion of a relatively high proportion of compost or other organic amendments in raised bed or cap-and-fill mixes. In in-ground systems, urban growers may apply amendments to mineral soils at rates far exceeding those recommended for commercial production. Spatial constraints on production may also lead growers to apply excessive amounts of fertilizer to crops in an attempt to maximize yield. Taylor and Lovell (2014) attributed available phosphorus and potassium levels as high as 1076 and 1236 mg kg^{-1} soil, respectively, across 31 Chicago home gardens to excessive use of synthetic fertilizers linked to the erroneous notion that higher nutrient concentrations would lead to higher yields.

The potential impact of legacies of soil contamination on human health is of particular concern in urban agriculture. The United States Environmental Protection Agency (USEPA) and the United States Department of Agriculture (USDA) recommend conducting a formal environmental assessment in areas of potential risk prior to establishing a food production site, as do some United States municipalities (Boston Public Health Commission, 2013; USDA, 2016; USEPA, 2011). This evaluation typically includes a survey of historical land uses followed by a soil sampling procedure that seeks to quantify contaminants of risk (USEPA, 2011). The USEPA suggests that lead, cadmium, arsenic, and zinc are some of contaminants of greatest concern in urban landscapes from sources that may include lead-based paint and leaded gasoline (Attanayake et al., 2014; Wortman & Lovell, 2013).

This combination of heavy metal contamination, nutrient enrichment, novel soil systems, and management strategies potentially influences biological processes in urban soils in unique ways compared to rural soils. Because different nematode families respond to soil physical disturbance and chemical conditions in distinctive ways, nematode trophic diversity and community structure potentially offer insights, as bioindicators, into soil food web functioning and soils' contributions to productivity. Opportunistic *r*-selected families, for example, may respond more positively to the high levels of nitrogen and organic matter enrichment in urban soils than *K*-selected families (Bongers, 1990; Ferris, Bongers, & de Goede, 2001; Wang & McSorley, 2005). The latter families, on the other hand, may be more sensitive to heavy metal pollution (Korthals, Bongers, Kammenga, Alexiev, & Lexmond, 1996; Shao et al., 2008) because they occupy higher positions in the trophic food web and consequently may be more likely to bioaccumulate contaminants in soils such as those found in urban agricultural production settings. The detrimental effect of heavy metal pollution on nematode communities has implications for understanding soil ecosystem functioning under these highly manipulated soil conditions.

Core Ideas

- Our study explores the influence of management on soil quality in urban agricultural sites.
- We also study the potential impact of soil heavy metal pollution on free-living nematodes.
- Management increased soil fertility to levels considered detrimental to water quality.

In an assessment of vacant urban lots and established urban community gardens in Akron and Cleveland, OH, USA, Grewal et al. (2011) reported optimal conditions for food production in both vacant lots and established gardens based on nematode community structure and microbial biomass. Soils in both vacant lots and gardens had high levels of nitrogen enrichment. However, the nematode community structure and trophic diversity were low to intermediate, suggesting that bacterial and fungal families with *r*-selected life history characteristics dominated the nematode community, possibly because of nitrogen enrichment and frequent soil disturbance. In a study of market and community gardens in Cleveland, OH, USA, Reeves, Cheng, Kovach, Kleinhenz, and Grewal (2014) similarly reported high enrichment index values for both garden types, indicating high nutrient availability. Other index values (structure, channel, and maturity) were low, reflecting relatively high levels of disturbance and dominance of the bacterial decomposition over the fungal pathway.

This study builds on the work of Grewal et al. (2011) and Reeves et al. (2014). While those studies focused on community and market gardens, our study expands the range of urban agricultural sites to also include home gardens. Though often overlooked by food activists, policymakers, and academics, home gardens appear to make a much larger

TABLE 1 Description of studied sites

Garden Code	Type	System	Media used for planting	Time since establishment	Approximate site area
				yr	m^2
CG1	Community	Cap-and-fill	Soil-compost mix	0	518
CG2	Community	In-ground	Native soil	70+	5907
CG3	Community	Cap-and-fill	Soil-compost mix	0	629
CG4	Community	Raised-bed	Soil-compost	0	531
CG5	Community	Raised-bed	Soil-compost mix	0	2046
CG6 [a]	Community	Raised-bed	Soil-compost mix	2	1593
CG7 [a]	Community	Raised-bed	Soil-compost mix	2	1593
FARM1	Farm	Cap-and-fill	Soil-compost mix	3	1596
FARM2	Farm	Cap-and-fill	Soil-compost mix	2	1374
FARM3	Farm	Cap-and-fill	Soil-compost mix	3	860
FARM4	Farm	Cap-and-fill	Soil-compost mix	1	1254
FARM5	Farm	Cap-and-fill	Soil-compost mix	10	1162
FARM6	Farm	In-ground	Native soil	4	355
HG1	Home	In-ground	Native soil	70+	146
HG2	Home	In-ground	Native soil	5	56
HG3	Home	In-ground	Native soil	0	35
HG4	Home	In-ground	Native soil	0	79
HG5	Home	In-ground	Native soil	0	22
HG6	Home	In-ground	Native soil	6	82
INST1	Institutional	In-ground	Native soil	17+	567
INST2	Institutional	In-ground	Native soil	5	1961

[a]CG6 and CG7 were located in the same community garden but were managed by different growers, and the mixes used were of different provenances.

contribution to the aggregate area of urban food production than do either community gardens or urban farms and consequently warrant greater attention from the scientific community. Our study also explores the potential impact of soil contamination by heavy metals—lead (Pb), arsenic (As), and zinc (Zn)—on nematode abundance and nematode community structure in urban agricultural soils. We hypothesized that nematode communities in soils with high levels of heavy metal pollution, nutrients/organic matter, or disturbance would be characterized by low levels of trophic connection and would be dominated by families with *r*-selected characteristics.

2 | MATERIALS AND METHODS

2.1 | Sites description and soil sampling

Urban home and community gardeners and farmers in the Chicago metropolitan area were recruited in the spring of 2014 through social media and personal contacts as part of a larger study, a participatory trial of tomato (*Lycopersicon esculentum* L.) varieties under conditions of urban production. Sites were initially classified based on the establishment method and scale of management using a criterion for land use application and scale similar to that suggested in (Lovell, 2010). Consequently, we classified study sites as: 1) private home gardens, 2) community gardens, 3) institutional farms, and 4) private urban farms. Descriptions of age, size, and cultivation method for each site are provided in Table 1.

The method of initial site establishment varied by site type (Table 1). Of the seven community gardens, only one was established in-ground, in native soil. The other six employed raised beds filled with a compost-top soil mix of unknown proportions or, in one case, windrows of mix on top of native soil. Similarly, production at only one of the six urban farms occurred in native soil; the other five farms mitigated soil contamination through cap-and-fill systems of varying configurations but generally characterized by windrows of compost-soil mix on top of wood chips. All six home gardens and both institutional sites were in-ground, with production occurring directly in native soil. Gardens in native soil were tilled, mechanically or by hand. Those employing raised beds or windrows of compost-soil mix were minimally tilled; mix depth ranged from 20.6 to 40.9 cm across sites. Reflecting growing enthusiasm for urban agriculture, four of the community garden sites were new in 2014, and one was only two years old. The sixth was founded during the Great Depression and was more than 70 years old. Most of the other sites were also relatively recent, having been established within the previous 10 years, though one home garden had been cultivated continuously since the 1930s, based on the owner's personal account.

Sites had been typically used for production of annual vegetable crops, including tomato (*Lycopersicon esculentum* L.), summer squash (*Cucurbita pepo* L.), pepper (*Capsicum anuum* L.), kale and collard greens [*Brassica oleracea* (Acephala Group)], and were generally surrounded by urban development. Three soil samples were collected from each site in May and June of 2014 using a 5-cm diameter soil probe to a depth of 15 cm. Soil samples were then kept at 3 ˚C until processed for soil nematode extraction, bulk density estimation, and chemical analyses.

2.2 | Soil analyses

Once in the laboratory, field moist samples were weighed and homogenized. A subsample was then used to determine soil moisture, which was needed to estimate bulk density using the core method. For this, we divided the estimate of the oven-dry mass by the known sample volume. The remaining sample was passed through a 25.4-mm sieve that allowed manual removal of large organic and inorganic materials and was split into subsamples used for nematode extraction and soil chemical analysis. Soil nematodes were extracted using procedures for the Baermann funnel extraction using a 20-g subsample in duplicates. Samples remained in the Baermann funnels for 48-hr periods to allow nematode migration from the soil samples to water, and settle. Once extracted, nematodes were heat killed and fixed in a glycerin/formalin solution at 60 ˚C. Nematodes were then counted prior to mounting on permanent slides for taxonomic identification at the family level and using keys from (Bongers, 1988). Nematode family abundances were then used to estimate indices of nematode community structure: the Maturity Index (MI) (Bongers, 1990), the Enrichment (EI), Structure (SI), and Channel (CI) Indices (Ferris et al., 2001). The MI is estimated based on the relative abundance of nematode families classified in the colonizer-persister (*cp*) scale. The indices of Ferris et al. (2001) are calculated based on the relative abundance of functional guilds along the enrichment or structure pathway.

All subsamples separated for soil chemical analyses were air-dried and then ground to pass through a 2-mm sieve. Indicators of soil fertility were quantified in a commercial soil testing laboratory using protocols recommended for the North Central Region of the U.S. Briefly, soil pH was determined on a 1:1 water and soil ratio and SOM by loss on ignition. Available P was determined using the Bray-P1 test solution while extractable nutrients (K, Ca, Mg, S, B, Fe, Mn, Cu, and Al) were determined on a Mehlich III extraction solution. The summation of exchangeable cations was used to determine CEC. Lead, As, and Zn concentrations in soils were also determined using a Mehlich III extraction solution. Mehlich III-based Pb values were used to estimate total soil Pb by USEPA methods after Minca, Basta, and Scheckel (2013).

2.3 | Statistical analysis

Differences in soil fertility characteristics along with total soil Pb and Ar were summarized by PROC MIXED in (SAS Institute, Cary, NC) using an incomplete randomized model as we had different numbers of gardens in each group category. Prior to analysis, variables that did not meet the assumptions of normality and homogeneity of variances were transformed using the natural logarithm function.

To evaluate the status of the soil food web and visualize differences along garden types, we ran non-metric dimensional scaling (NMDS) on a Bray-Curtis dissimilarity matrix using the *metaMDS* function in the "vegan" package (Oksanen, 2015) in RStudio. To understand the relationship of nematode families to the soil environment described with indicators of soil fertility, bulk density, and heavy metal concentration we used the function *envfit* within the "vegan" package (Oksanen, 2015). This function fits vectors that depict the environmental variables and the direction and length reveal the strength and direction of relationships with nematode communities along the ordination gradient (Oksanen, 2015).

3 | RESULTS AND DISCUSSION

Community gardens had a higher proportion of bacterial feeding nematodes (Figure 1) compared to home gardens and institutional farms (P value = .01). Members of the families Rhabditidae, Diplogasteridae, and Cephalobidae dominated the nematode communities in soils from community gardens. Institutional farms and home gardens, on the other hand, had a greater proportion of plant parasitic families than community gardens (P value = .001), with a greater abundance of individuals from the families Hoplolaimidae, and Pratylenchidae. The proportions of fungal feeders, predatory and omnivore families were similar across garden types. When averaged across sampled locations, bacterial feeding nematodes dominated the communities of sites employing compost-soil mixes in aboveground systems—whether raised beds, windrows, or cap-and-fill systems—compared to those established in-ground.

Similar Maturity Index (MI) values, ranging from 2.03 to 2.67, across site types suggest all of the locations experience similar levels of disturbance and that communities are represented by greater proportions of opportunistic families with low values along the *cp* scale. Similarly, values

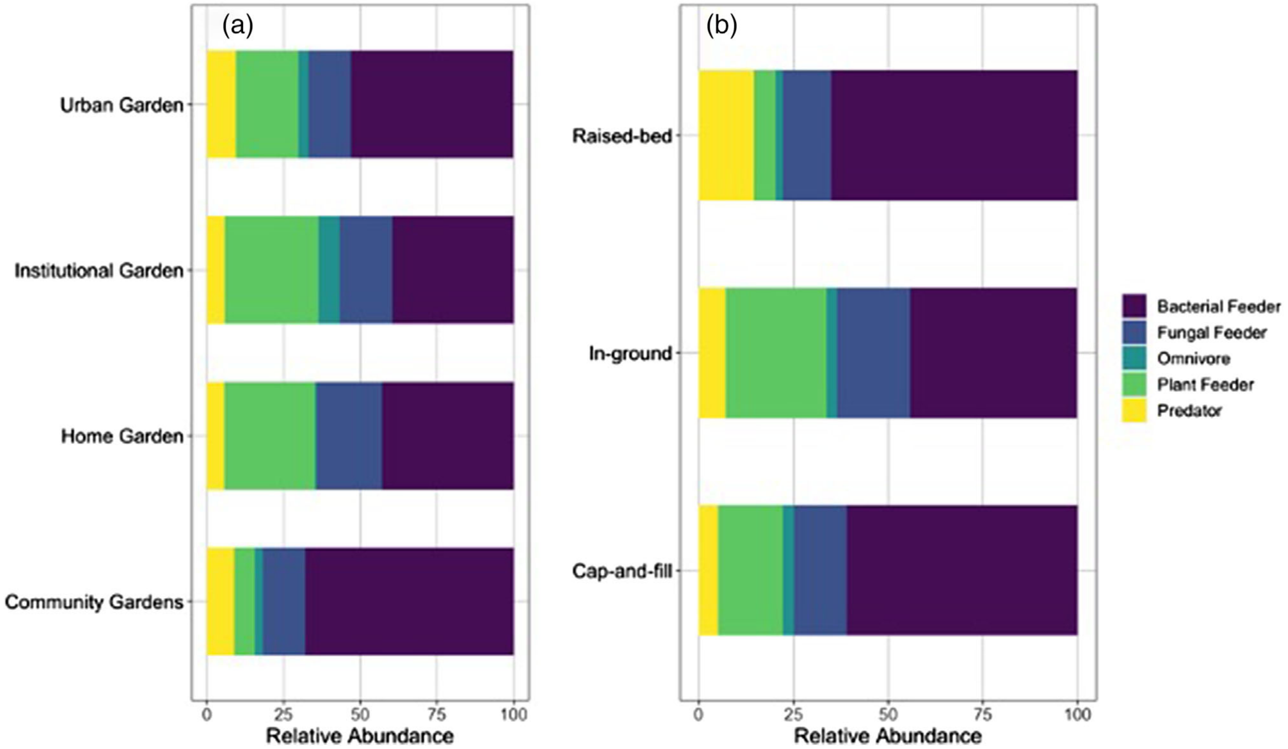

FIGURE 1 Relative abundance of nematode trophic groups based on a) site class (community and home gardens, and urban and institutional farms) and b) main media arrangements used for production (cap-and-fill, in-ground, and raised bed)

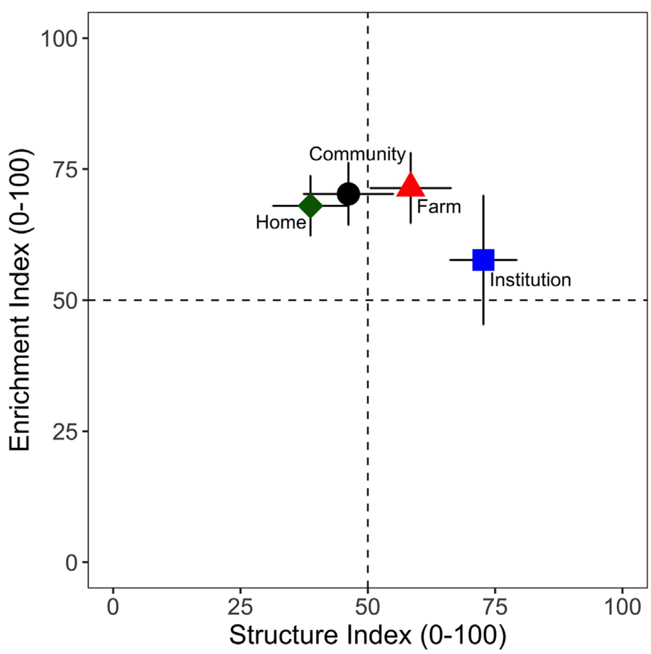

FIGURE 2 Faunal profile of nematode communities in urban gardens and urban farms in Chicago, IL

computed for the Enrichment Index (EI), indicate the presence of families responsive to organic matter enrichment (Figure 2). Values were similar across community and home gardens as well as urban farms. The Channel Index (CI) is the ratio of opportunistic fungal to bacterial feeding nematodes; consequently, it is an indicator of the dominant decomposition pathway in a food web. In this specific case, the CI revealed a food web dominated by bacterial-feeding nematodes in community gardens and urban farms. In home gardens and institutional farms, however, we observed a dominance of the fungal decomposition pathway. These results may, in part, be explained by the method of initial site establishment and the relative level of soil disturbance. As noted above, the majority of community gardens and urban farms were relatively recently constructed using imported soil-compost mixes, while home gardens and institutional farms were established directly in native soil. Consequently, the level of soil disturbance associated with continuous importation and mixing of media off-site may have, overall, been much greater in community gardens and urban farms than in home gardens and institutional farms.

Another indicator of the status of the soil food web is the Structure Index (SI, Figure 2), which is calculated based on the abundances of predatory and omnivorous nematodes and long-lived bacterial and fungal feeding nematode families. The SI quantifies the level of complexity in the food web, the number of linkages among members of the food web. Higher values indicate the presence of nematode families with longer life spans and those classified within the *cp* classes 3–5 in (Bongers, 1990). These are larger organisms in terms of body size. In this study, nematode communities in institutional farms had significantly greater SI values than the other three classes. This is likely linked with the intensity of soil disturbance as reflected in the values for bulk density and soil organic matter; though tilled, these institutional sites may have been less affected by practices that incorporate external loads of residue or compost, which would favor more opportunistic nematode taxa with lower *cp* values.

While some sources suggest that nematode families ranked with high *cp* classes can be sensitive bioindicators of heavy metal pollution, they are also negatively affected by physical disturbance. The mixing and turning of soils for bed preparation and weed control—or the blending of mineral soil and compost to create mixes for raised beds and cap-and-fill systems—shifts the community to an earlier stage of secondary succession and to the dominance of colonizer or opportunistic families ranked in the low *cp* classes. Even though the SI values from this study are higher than those previously reported in urban gardens from two other midwestern cities (Grewal et al., 2011) they still reflect varying levels of community linkage within the soil food web and related to recent disturbance. The majority of the sampled sites, for example, had only been recently established, while the institutional and urban farms were more than two years old at the time of sample collection. Consequently, the SI values for the urban farms and institutional gardens were more similar to those from less disturbed agricultural sites or natural systems (Sánchez-Moreno, Smukler, Ferris, O'Geen, & Jackson, 2008; Ugarte, Zaborski, & Wander, 2013). Furthermore, we only had access to two institutional farms, which may not necessarily represent the variability present across a larger set of sampling locations.

The non-metric multidimensional scaling (NMDS) for nematode families revealed distinctions between the nematode community structure across class groups. Along the *x*-axis, community gardens plotted away from urban and institutional farms. Along the *y*-axis, we observed wider differences between community gardens and the other three class groups (Figure 3). To explore the hypothesis that soil quality parameters and the concentration of heavy metals influence nematode community composition, we fit environmental vectors to the NMDS plots. The length of the vectors and their distance to nematode communities reveal the strength of their relationship. In this particular case, we found that soil OM and pH had the greatest influence in this dataset. Both variables were positively related with nematode community structure in community gardens. Surprisingly, the strength of relationships of Pb and available P with nematode communities was not apparent. The wide range of concentrations across the studied sites may account for the weak relationships. In the case of Pb, it is also possible that the observed concentrations were within the levels of tolerance for sensitive nematode families. In Shao et al. (2008) for example, they reported a negative correlation between nematode family abundance in

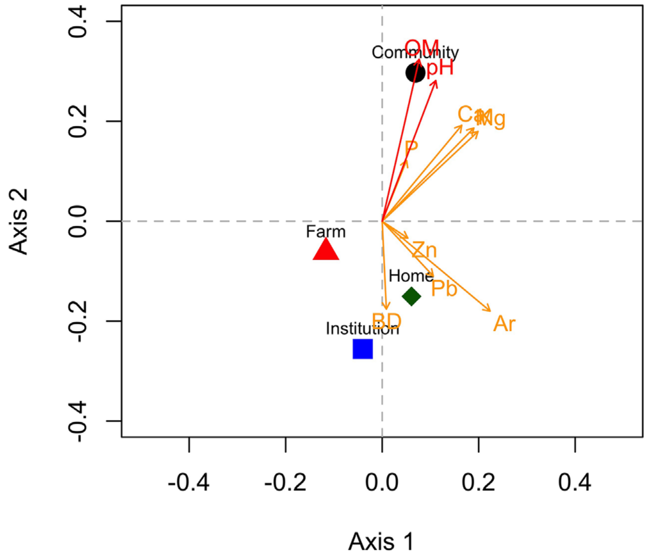

FIGURE 3 Non-metric multi-dimensional scaling of free-living nematode families. Vector arrows indicate soil parameters that may influence nematode community structure in urban gardens and urban farms in Chicago, IL

higher *cp* classes and lead concentration, but the levels of pollution were greater than 3,000 mg kg^{-1} soil, almost an order of magnitude higher than the highest lead concentration in this study using the Mehlich III extraction method.

Descriptive statistics for soil contaminants revealed a wide range of concentrations (Table 2). In general, total soil Pb, As, and Zn ranked highest in home gardens (mean = 141.2, 7.4, and 52.8 mg kg^{-1} soil, respectively) and lowest in urban farms (mean = 42.2, 5.0, and 32.7 mg kg^{-1} soil, respectively). Within the former category, one of the six sites had total Pb levels higher than 400 mg kg^{-1} soil; also, two sites had total Pb concentrations >300 and <400 mg kg^{-1} soil. The lower mean lead levels found for urban farms and community gardens are comparable to those reported by Witzling, Wander, and Phillips (2010) for raised bed growing areas in Chicago community gardens and reflect the contaminant mitigation strategies (raised beds and cap-and-fill systems) generally employed at these sites.

Though no U.S. government agencies have defined a level of concern for soil Pb concentration for food production, total Pb concentrations across our study sites, with the exception of one home garden, never exceeded the threshold of 400 mg kg^{-1} soil suggested by the USEPA and others for children's play areas and frequently cited in the literature as a proxy threshold for UA. (See reference list of Witzling et al., 2010). On the other hand, As and Zn were not contaminants of concern in the sampled sites. Across locations, concentrations were below the 16 mg As kg^{-1} soil and 2200 mg Zn kg^{-1} soil suggested as thresholds in Mitchell et al. (2014).

Indicators of soil fertility revealed excessive concentrations of nutrients across sampled locations, regardless of

TABLE 2 Summary of soil tests and tomato yield on samples collected from community and home gardens, institutional and urban farms in Chicago, IL. Values represent raw means ± one standard deviation

Parameter	Community Garden	Urban Farm	Home Garden	Institutional Garden	ANOVA *P* value
Soil pH	7.7 ± 0.2	7.7 ± 0.4	7.4 ± 0.3	7.6 ± 0.1	.0792
Soil organic matter (%)	13.3 ± 6.1	17.9 ± 8.4	6.6 ± 1.7	5.3 ± 0.8	.0029
Available P (mg/kg)[a]	169.9 ± 97.4	225.4 ± 74.2	95.8 ± 88.4	94.3 ± 28.2	.0167
Exchangeable K (mg/kg)[a]	936.0 ± 874.0	924.7 ± 484.3	344.9 ± 213.4	347.8 ± 85.0	.0506
Exchangeable Ca (mg/kg)[a]	3612.4 ± 816.2	4365.1 ± 2703.4	2907.0 ± 257.1	2634.2 ± 235.7	.0591
Exchangeable Mg (mg/kg)	762.7 ± 270.2	726.1 ± 133.4	716.5 ± 118.0	681.5 ± 134.0	.9470
Total Pb (mg/kg)[a]	66.5 ± 72.5	42.2 ± 12.6	141.2 ± 119.4	89.54 ± 42.4	.0024
Arsenic (mg/kg)[a]	6.5 ± 3.1	5.0 ± 2.3	7.4 ± 1.5	5.3 ± 0.7	.1034
Zn (mg/kg)[a]	46.0 ± 46.5	32.7 ± 36.0	52.8 ± 45.9	51.2 ± 36.5	.6092
Bulk density (g/cm^3)	1.1 ± 0.3	1.0 ± 0.4	1.7 ± 0.3	1.7 ± 0.1	.0014
Yield (kg/m^2)	3.6 ± 1.8	4.4 ± 1.9	5.3 ± 1.0	7.1 ± 0.7	.0117

[a]Indicates variables that were transformed using natural logarithm prior to statistical analysis.

class groups. For instance, mean concentrations of available P ranged from 94 to 225 mg kg^{-1} soil, exceeding by far the recommended levels of 15 to 35 mg kg^{-1} soil for food production in this region (Fernández, Farmaha, & Nafziger, 2012). Similarly, values for exchangeable K ranged from 345 to 936 mg kg^{-1} soil, compared to the recommend range of 130 to 200 mg kg^{-1} soil for optimum production (Fernández et al., 2012). Excessive nutrient levels are likely the result of overuse of external inputs, either at the time of garden establishment or during subsequent site management (Taylor & Lovell, 2014, Witzling et al., 2010). Small et al. (2019) found that urban growers' N and P application rates—primarily in the form of organic amendments—were 10 and 30 times greater than rates in commercial farm production, respectively, resulting in very low rates of N and P use efficiency (5% and 2.5%, respectively) for urban production. In this study, the excessive levels of P and K observed in community gardens and urban farms did not contribute to greater tomato yields, as institutional farms and home gardens—which on average had lower soil concentrations of P and K—had higher average tomato yields (Table 2).

Urban agriculturalists' use of compost, whether as a media component in raised-bed and cap-and-fill mixes or as an input to native soils in in-ground production, has a beneficial effect on soil bulk density, as has been suggested in other studies of UA (Moskal & Berthrong, 2018). The threshold level for bulk density that restricts root growth ranges from 1.47 g cm^{-3} in clay soils to greater than 1.8 g cm^{-3} in sandy soils. In this study, average bulk densities were quite low for community gardens and urban farms, 1.11 g cm^{-3} for the former and 1.01 g cm^{-3} for the latter, reflecting the high proportion of compost-rich mixes used in these systems. Values for home gardens and institutional farms, were quite high—1.73 and 1.66 g cm^{-3} on average—for the clayey and silty soils found in the Chicago region, reflecting lower levels of organic inputs and the compaction associated with urbanization. These high values for bulk density underscore the need for urban growers gardening in native soil to implement management strategies that mitigate and reduce soil compaction, including broadforking and cover cropping, which disrupt compacted layers. Producers can also prevent future compaction by implementing practices such as mulching of paths and reduced traffic in planting beds.

Compost may be frequently used as a mix component in raised beds and cap-and-fill systems because of its lighter weight and reduced transportation cost relative to mineral soils. It is also perceived as environmentally friendly, with benefits to soil fertility and physical soil structure. Compost use has additional positive agronomic effects in raised bed production, with increased yields reported for leafy greens such as cilantro and kale (Moskal & Berthrong, 2018), though the N use efficiency of these systems has not been evaluated. The benefits of compost use must be weighed against its potential ecosystem disservices. Compost additions enhance microbial functions that promote the degradation of soil organic matter and release of inorganic N and P (Lazcano, Gómez-Brandón, Revilla, & Domínguez, 2013). The excessive levels of SOM and available P observed in community gardens and urban farms, in particular, suggest that the rate of nutrient release from mineralization might be greater than the rate of nutrient assimilation by crops. We recommend that the "more-is-better" approach to organic matter management be reconsidered in UA; excessive additions of nutrient rich organic amendments in UA may increase the potential for nutrient loading to stormwater through runoff and leaching, and thus reduce the ecological benefits associated with urban gardens.

Similarly, these potential ecosystem disservices must be weighed against the potential services of maintaining high levels of inorganic P in contaminated urban soils with amendments that contribute to the reduction of Pb bioavailability (Wortman & Lovell, 2013). Compost additions directly reduce contaminant concentrations in the soil through immobilization of available Pb mediated by the formation of lead-phosphate minerals (Wortman & Lovell, 2013). In nutrient limited environments, high organic matter inputs may also indirectly contribute to the dilution of contaminant concentrations in harvested plant tissue by increasing crop growth and harvested biomass (Attanayake et al., 2014). Amending urban agricultural soils with organic matter can be a more cost-effective approach to mitigating sites with low levels of contamination than removing and replacing the contaminated soil or capping and filling the site with clean compost-based media, which Cunningham and Berti (2000) estimated could cost \$130,000 ha^{-1}.

Contaminant levels, however, vary widely in urban environments (Taylor & Lovell, 2015; Witzling et al., 2010). Taylor and Lovell (2015), for example, found that soil Pb levels ranged from 60 to 992 mg kg^{-1} soil in 31 sampled Chicago home gardens of Chinese-origin, Mexican-origin, and African American households, with group means (337–363 mg kg^{-1} soil) below the mitigation threshold level (400 mg kg^{-1} soil) recommended by the USEPA for children's play areas. Given the relatively low concentrations of contaminants in this study and the low bioavailability of contaminants such as soil Pb to many crop plants (Brown, Chaney, & Hettiarachchi, 2016), we urge: 1) soil testing for all sites of UA production, including home gardens; 2) the implementation of strategies such as mulching and surface till that reduce contamination risk on soils with a legacy of urban pollution; 3) the judicious use of inorganic P and compost for remediation purposes, and 4) the production of non-root crops and selection against species and varieties demonstrated to be hyperaccumulators.

Furthermore, we encourage the application of soil amendments based on crop needs. Nutrient use efficiency in urban agriculture could be enhanced and the potential for ecosystem disservices reduced through education and outreach efforts that bring awareness about the impact of management practices. Soil testing appears to be rare in urban agriculture (Small et al., 2019; Taylor & Lovell, 2014), and growers may be unaware of opportunities for increasing nutrient use efficiency and reducing input costs by matching nutrient availability to crop need. Urban agriculture service providers, government agencies, and the grey literature may attempt to reduce the cognitive load of nutrient management through one-size-fits-all heuristics that may have negative economic and environmental implications. The City of Chicago's home composting program, for example, recommends tilling a 10- to 20-cm layer of compost into new garden beds followed by an additional incorporation of 2.5 to 7.6 cm of compost every year (City of Chicago, 2009). Similarly, Jeavons (2012) suggests adding up to 2.5 cm of compost at the beginning of every 4-month crop turn in biointensive production, a popular model for urban farming. In most urban production systems, these rates of compost application are likely to lead to excessive nutrient accumulation and, consequently, to water pollution.

Because of differences in scale, inputs, and context, agronomic research on commercial farming practices may not provide adequate guidance for the development of alternatives to this perceived standard of management. Instead, experimental research is needed to develop scale-appropriate best management practices that help gardeners and farmers maximize the ecosystem services of urban food production systems while minimizing their disservices (Taylor, 2020). For example, sites identified with excessive inorganic P values in a soil test would benefit from the use of plant-based fertility instead of compost-based materials. This can be achieved by incorporating cover crops between periods of production. Cover crops are able to maintain ground cover at times when the weather is not suitable for food crops and thus maintain production of root biomass, which in turn fuels biologically active soil communities. Legume cover crops can supply N fertility whereas non-legume cover crops contribute to tightening the nutrient loop within the garden system and to building slow cycling soil organic matter.

The majority of research on cover crops, however, has been done in larger scale production systems. The challenges associated with managing cover crops in urban gardens are related with the limited area available for the production system, and reduced knowledge about their cultural practices (i.e., seeding rates, planting, and termination method). Schonbeck, Elder, and DeGregorio (1996) proposed using a mixture of leguminous and non-leguminous species with shallow root systems which can be easily managed by the practitioner using tools available to gardeners. Further studies should focus on understanding the physiological response of cover crops to the urban micro-climate and on the quantification of their specific functions including their influence on the organisms known to contribute to nutrient cycling and food web structure.

4 | CONCLUSION

This study and others indicate that urban growers often manage their soils in ways which undermine the ecosystem services provided by their farms and gardens, including nutrient cycling and provisioning. Furthermore, management practices may be a source of ecosystem disservices, e.g., nutrient loading of urban stormwater. Given the sense of stewardship that these growers—much like rural farmers—may feel toward their land (Sonti & Svendsen, 2018), we assume that these practices are a result of a lack of guidance on best practices for soil management in urban agriculture, which in turn may stem from 1) a lack of outreach to urban growers and 2) a dearth of scientific evidence on which to base the development of BMPs. Gardeners and farmers are natural experimentalists, often hungry for information and willing to try new crops and techniques (Taylor & Lovell, 2015). We encourage agronomists and others to reach out to urban growers as potential participants in *in situ* and *ex situ,* scale-appropriate experimental research on urban production systems, to maximize the contributions of urban agriculture to urban social-ecological systems and to minimize its harms.

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