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Testing and educating on urban soil lead: A case of Chicago community gardens

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Abstract

Chicago has many urban agricultural projects that provide a source of local food for city dwellers. Urban garden soil, however, may contain lead pollution, and soil quality can vary dramatically from location to location. Soil testing and access to information should improve gardeners' abilities to grow food safely in urban soils, and to know if time-consuming or expensive measures to avoid lead exposure or enrich the soil are really necessary for their gardens. Soil quality including lead levels was profiled in 10 Chicago gardens. Gardens growing food within raised beds were compared to gardens growing food without raised beds. We also quantified lead in adjacent areas of bare soil or where children might play. Soil lead was measured in two ways: through acid digestion with the Environmental Protection Agency (EPA) 3050B method and a Mehlich-III extraction. The overall mean soil lead level reported through the EPA method was 135 parts per million (n=86), with a range from 10 parts per million to 889 parts per million in individual soil samples. The average for the Mehlich-III method was 63 parts per million. Lead levels in most gardens were not a concern, although gardens contained excessive fertility. Use of raised beds reduced lead levels and thus the potential risk of lead ingestion from plant uptake, but further study comparing the use of raised beds with a greater number of gardens is required. Higher lead levels in soil from nearby areas suggest the possibility of contamination to raised beds and supports the notion that areas with bare soil adjacent to gardens may be an equal or greater source of risk. Our results suggest that the Mehlich-III soil test was positively correlated with the more costly EPA test and could be developed as less expensive test easily conducted by commercial soil-testing labs. Additionally, a training pro-

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gram about urban garden safety with live and online options was created and evaluated with questionnaires given to Master Gardeners. Both live-trained and online-trained groups' quiz scores improved significantly after the trainings, demonstrating that education about urban soil management can be effective.

Keywords
community garden, lead, soil testing, urban agriculture, urban soil, Chicago, training, web-based learning

Introduction

Urban gardening is a popular activity that offers many benefits to participants and communities. The nonprofit organization GreenNet documents over 600 community gardens in Chicago (GreenNet, no date). Access to fresh food in Chicago is also important, as more than half a million people in Chicago live in food deserts (Mari Gallagher Research & Consulting, 2006). Urban gardening projects can offer neighborhood stability, create a place for interracial connections, and help participants meet self-esteem and social needs (Shinew, Glover, & Parry, 2004; Tranel & Handlin, 2006; Waliczek, Zajicek, & Lineberger, 2005).

Urban garden settings, however, may contain contaminants that pose risks to gardeners, children who play in or near the gardens, and consumers of garden produce. Research shows that seasonal peaks in human blood lead levels correspond with environmental conditions, such as warm temperatures, low soil moisture, and greater amounts of wind, that result in increased suspension and movement of small soil particles (Laidlaw, Mielke, Filippelli, Johnson, & Gonzales, 2005). Urban soil can contain elevated amounts of lead because the tiny, insoluble lead particles become bound to small soil particles. Even though the addition of lead to gasoline and paint was phased out in the 1970s, these sources remain in urban soil and can be the primary contributors to lead in urban soils (Clark, Brabander, & Erdil, 2006). The Centers for Disease Control and Prevention (CDC) reports that of the more than 3,500,000 children in the U.S. under three years old tested for blood lead levels in 2007, about 1.00% had elevated blood lead levels, defined as more than 10 micrograms per deciliter (CDC, 2009). Among the 23,434 children under six years old tested in 2008 in Cook County, where Chicago is located, the percentage of children with elevated blood lead levels was 7.23% (CDC).

While the negative effects of lead exposure are indisputable, deciding the degree to which soil lead in gardens used for growing food poses a health risk is challenging because lead has complicated soil chemistry, soil sampling methods may affect the level of lead detected, and exposure to soil lead in gardens used for growing food can occur both through soil ingestion and by consumption of produce grown on contaminated soil.

Currently, the most common Environmental Protection Agency (EPA) method for measuring soil lead uses a very strong acid to remove almost all of the lead from a soil sample (known as an acid digest) (U.S. EPA, 1996). Alternatively, much research is devoted to finding an *extraction* method that measures only bioavailable forms of lead. Bioavailable forms of lead are of interest because these are the forms of lead a plant may uptake more easily, and consumption of contaminated edible plants is one route of human exposure to lead. Simple extracts like Mehlich-I and Mehlich-III are attractive options since these are routinely used by commercial soil testing labs and cost less than the acid digest method.

Soil sampling methods are a key and challenging aspect of testing for soil lead. In general, sampling strategies emphasize surface soil since lead can accumulate there in insoluble forms (Laidlaw & Filippelli, 2008), though other research suggests that in gardens where soil is mixed, lead can be homogenous to the root zone (Clark, Hausladen, & Brabander, 2008). Studies also suggest that a risk to lead exposure is posed by soil in areas adjacent to gardens, so sampling bare paths or areas in which children might play may be important (Clark et al., 2008; Binns et al., 2004). Finally, understanding and predicting the risks of soil lead are particularly difficult in gardens used for growing food because

Table 1. Soil lead level limits for growing food in gardens

Limits†	Source
At more than 100 parts per million lead, do not grow food crops in the garden with children. Without children, 300 parts per million lead or less is acceptable.	Rosen, 2002
At 400 parts per million lead or more, do not grow food crops in the soil.	Finster, Gray, & Binns, 2004
Between 400 and 1,000 parts per million lead, do not grow leafy greens or root crops. Above 1,000 parts per million lead, do not garden in the soil.	Stehouwer & Macneal, 1999
Between 400 and 1,200 parts per million lead, do not grow leafy greens or root crops in the soil. Above 1,200 parts per million lead, do not grow food crops in the garden soil.	Angima & Sullivan, 2008
Between 500 and 1,000 parts per million lead, do not grow leafy greens and root crops. Above 1,000 parts per million lead, do not garden in the soil.	Logan, 1993

† Assume soil testing for lead with EPA Method 3050B.

of the multiple ways in which soil lead is ingested, directly through soil and by consumption of produce grown on contaminated soil.

In order to establish a soil lead level for gardening edible plants that would not result in elevated blood lead levels, one would need to know the level of lead in the soil, amount of that lead in soluble forms, rate of soil ingestion, amount of lead absorption by edible plants, amount of produce consumed, and factors that affect how lead behaves in the human body, including the consumer's age and nutrition. Several researchers have created risk assessment models for lead and growing food in urban soil, though none has recommended a single cutoff level for soil lead and gardening (Clark et al., 2008; Hough et al., 2004; Carlisle & Wade, 1992). The EPA recommends soil lead levels under 400 parts per million for areas where children play (U.S. EPA, 2001), but there are no specific EPA guidelines for soil lead and growing food in gardens. Some Extension agencies and researchers do suggest specific limits when a soil test indicates that growing food in a garden is not safe due to lead levels, but suggestions vary widely (table 1). The lack of standard EPA guidelines for lead in garden soil used for growing food, inconsistent recommendations from various Extension agencies, and the fact that lead testing services are not easily accessible, leave urban gardeners guessing about risk.

Numerous agencies and studies suggest using raised beds with imported soil materials as a technique for urban gardeners to avoid or reduce lead exposure (Angima & Sullivan, 2008; Chicago Park District, 2008; Stilwell, Rathier, Musante, & Ranciato, 2008; Finster, Gray, & Binns, 2004; Peryea, 1999; Stehouwer & Macneal, 1999; Logan, 1993). This can be cost-prohibitive for many gardeners and large community gardens. Little research has been done to verify this solution. Stilwell et al. (2008) measured lead concentrations in 25 urban gardens and found that those using raised beds did not contain lead levels that exceeded the limits for Connecticut residential soil (not specifically garden soil for food growing) where their research took place. Clark et al. (2008) found lead levels in raised beds increased from an initial range of 110 to 190 parts per million to an average of over 300 parts per million in just four years. This is likely due to the accumulation of small soil particles contaminated with lead or lead dust from surrounding areas, which Caravanos, Weiss, and Jaeger (2006) suggest are being continuously deposited. Some community groups and Extension services provide information about raised-bed construction, but numerous unaddressed issues include where to purchase fill materials for raised beds, what materials are safe for raised-bed construction (e.g., untreated lumber), how to validate that soil materials are uncontaminated and of high quality, and which (if any) organic amendments might aid in reducing metal availability, as some research suggests.

Because of the potential for contamination, access to resources about urban soil risks is critical. Web-based learning, in particular, could offer many benefits. Potential advantages of web-based learning include increased accessibility to information and the ability to easily cross-reference materials (Chumley-Jones, Dobbie, & Alford, 2002). Agius and Bagnall (1998) state that learning through the Internet is a resource-based approach that promotes "learner autonomy" and presents the opportunity to incorporate numerous styles of learning. Much research has evaluated the use of online learning methods specifically for gardeners. Meyer and Foord (2008) found that 28% of surveyed gardeners reported that they were very likely to use the Internet to solve a question about a plant problem. VanDerZanden and Kirsch (2003) found that 85% of surveyed Oregon Master Gardeners, a group of volunteers given formal training by Extension services, used computers and 92% of those used the Internet, suggesting that Master Gardeners may be open to taking training courses online. Typical Master Gardener demographics (over 40, well educated, motivated) are conducive to distance learning (Jeannette & Meyer, 2002). It is unclear whether this group would have the same learning preferences as younger or more diverse urban populations who garden.

It is also unclear whether gardeners would use the Internet to learn about environmental risk. The wealth of information about soil fertility and environmental risk in scientific journals may be overlooked by urban gardeners lacking access to the information or the time to interpret it. After reviewing online resources that address urban gardening risks, we found few sources that encourage soil testing for metals like lead or have information about how to find a soil testing lab that will measure pollutants and interpret soil test results. Some websites misinterpret EPA guidelines for soil lead, erroneously reporting that the EPA has guidelines for soil and growing food in gardens. Most sites that do offer information about safety and urban gardening are completely text-based and do not use interactive multimedia, such as videos or audio clips, the use of which can increase learner knowledge (VanDerZanden & Rost, 2003). Most websites also miss the opportunity to link the public to in-depth research articles or abstracts. It is not clear whether gardeners have, want, or would benefit from access to information about urban soil management and potential risks.

Study Objectives

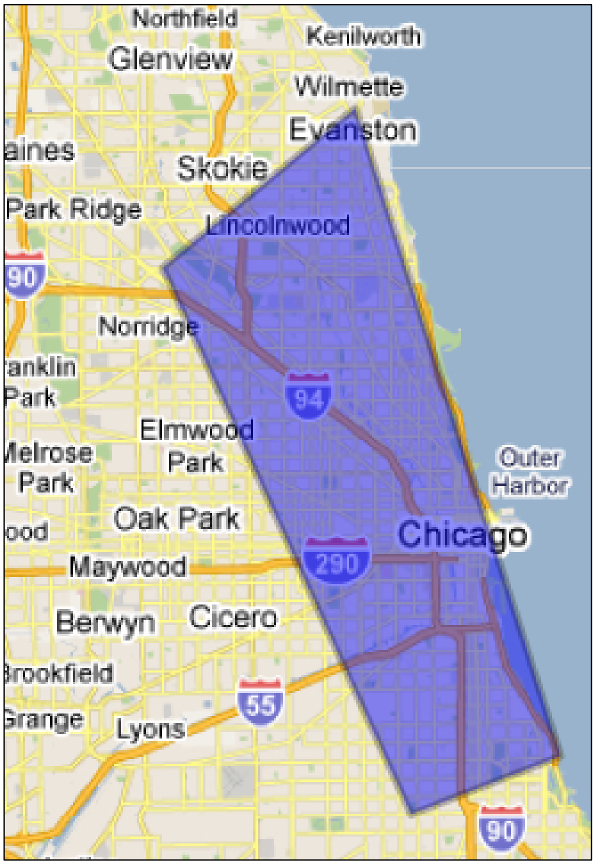
The objectives of this research were to: (1) create soil quality profiles of 10 urban gardens in Chicago for use as explanatory tools, (2) evaluate the differences in soil quality profiles between raised-bed food-growing areas, non–raised-bed food-growing areas, and other nearby garden areas such as pathways and exposed soil, (3) compare the evaluation of soil lead through both a strong acid digestion (the EPA method) and an extraction (the Mehlich-III method), and assess the tests' predictive capabilities through a lettuce bioassay, and (4) determine whether a live and/or online delivery of educational materials about urban soils management and risks might benefit urban gardeners.

Methods

Study of Garden Soils

We sampled 10 gardens in a transect of Chicago approximately 20 miles long (figure 1). These were distributed to cover a larger geographic space than many of the other studies conducted to date. The gardens were paired to represent raised-bed and non–raised-bed gardens. Soil was sampled from the gardens in late May and early June of 2008. A total of 86 soil samples (zero to 30 centimeters deep with a five centimeter diameter volume corer) were taken from the 10 sites. At most sites, four soil cores were taken from food-growing areas and three soil cores from nearby areas of soil not used for growing food (such as exposed soil in pathways or places where children play). In gardens where

Figure 1. General location of sampled gardens in a transect of Chicago, approximately 20 miles long



Source: Google Maps map provided by authors.

Figure 2. Example of a raised-bed community garden sampled in this study

Photo provided by authors.

Figure 3. Example of a non–raised-bed community garden sampled in this study

Photo provided by authors.

food was grown in both raised beds and in non–raised-bed areas, four cores were taken in each type of area. In garden sites with two distinct gardening areas, four cores were taken in each area.

Soil analysis was conducted with the following techniques:

- Texture, using the hydrometer method (Gee & Bauder, 1979)
- Particulate organic matter (material > 53 micrometers), separated from bulk soil (Marriott & Wander, 2006)
- Percent organic matter through loss on ignition, samples sent to Brookside Laboratories, Inc., in New Knoxville, Ohio (Gavlak, Horneck, Miller, & Kotuby-Amacher, 2003)
- pH with a 1:1 water method at Brookside Laboratories, Inc. (Gavlak et al., 2003)
- Potassium, phosphorus, copper, aluminum, and zinc with a Mehlich-III extraction at Brookside Laboratories, Inc. (Gavlak et al., 2003)

- Plant-available nitrogen was estimated based on percent organic matter by Brookside Laboratories, Inc.

- Lead determined with a Mehlich-III extraction at Brookside Laboratories, Inc. (Gavlak et al., 2003)

- Lead determined through EPA Method 3050B using inductively coupled plasma analysis at Brookside Laboratories, Inc. (U.S. EPA, 1996)

Lettuce Bioassay

The lettuce variety "Little Gem" was used to test plant uptake of lead from the soil. Seedlings were grown in 70 grams of soil from the food-growing areas of the gardens to directly evaluate plant uptake. Two seeds were added to each cell and thinned to contain one plant per cell. Flats were fertilized to avoid nutritional limitations and were rotated regularly in the greenhouse. After 30 days, lettuce was harvested. Each plant was gently rinsed with water in a sieve under the tap to wash away soil particles, then rinsed in soapy water, then washed again with tap water, and finally washed with deionized water. Roots were separated from the leaves and stems, and plants were then oven-dried and ground. Plants were analyzed for lead content at Brookside Laboratories, Inc., using inductively coupled plasma analysis after acid digest with the EPA method 3050B (U.S. EPA, 1996). To meet weight requirements for analysis, the roots or shoots (leaves plus stems) were pooled for some gardens.

Study of Educational Materials

Topics for the educational materials were chosen based on gaps in existing online resources and focused on organic amendments, testing garden soil, soil lead and fertility recommendations, ways to limit lead exposure, and research about avoidance tactics. Confusing or inaccurate information on existing websites was specifically addressed to provide clarification. Credible sources (peer-reviewed research, EPA publications, and Extension fact sheets) offering information on urban soil and lead ingestion were incorporated into the training materials. The materials were converted to a PowerPoint presentation for the live trainings and to a website for the online trainings (ASAP, 2009). We prepared four short videos, each less than three minutes long, for the online training. The video topics were (1) how to sample soil for lead, (2) how to interpret soil test results, (3) tips for limiting exposure to lead, and (4) organic amendments. Other content for both the online the live trainings included information about our research—how and why it was conducted—in the context of the topics previously listed. We illustrated points with pictures, such as different kinds of organic amendments, and graphs, such as a chart showing how as pH increases (becomes more basic), the solubility of lead of decreases.

Pre- and postprogram questionnaires were developed in compliance with the Institutional Review Board at the University of Illinois at Urbana Champaign to evaluate knowledge gains through responses to quiz questions, and evaluate whether participants perceived knowledge gain from the trainings. Identical quiz questions on the pre- and postprogram questionnaires asked about historical sources of lead exposure in the garden, methods to limit lead exposure, and soil lead level guidelines. Participants were also asked to rank their level of knowledge about soil quality, soil contamination, and soil testing before and after the trainings.

Master Gardeners were invited through email to attend an urban soils workshop at the Garfield Park Conservatory. After filling out a preprogram questionnaire, a live presentation was given about urban soil issues including the content described above. After the program, participants filled out a postprogram questionnaire. Master Gardener volunteers who indicated interest in the program but could not attend were invited to use the online training module. Additional participants for the online training were recruited through email by Master Gardener coordinators in Chicago and collar counties.[1] Gardeners in Chicago collar

[1] The Illinois collar counties are Dupage, Kane, Lake, McHenry, and Will. Chicago is in Cook County.

counties were assumed to live and garden in urban or peri-urban environments that have similar risks. Via email, participants were sent links and instructed to take the preprogram questionnaire, explore the online training module, and then immediately complete a postprogram questionnaire.

Statistical Analysis

The MIXED procedure in the software program SAS (PROC MIXED, SAS v9.1.3, SAS Institute, Cary, NC, USA) was used to compare different garden areas based on least-squares means for the variables organic matter, estimated nitrogen release, phosphorus, potassium, pH, EPA lead, Mehlich-III lead, aluminum, copper, and zinc. The three types of garden areas (raised-bed, non–raised-bed, other nearby areas) were treated as fixed effects and garden site was a random effect. All variables except for aluminum and pH were not normal and were transformed before analysis. Simple regression was used to evaluate the relationship between Mehlich-III and EPA lead and between lead concentration in lettuce leaves and soil lead fractions. Sample sizes of roots were too low to perform meaningful analyses between root lead and soil lead levels.

Stepwise multiple regression analysis (PROC REG, SAS v9.1.3, SAS Institute, Cary, NC, USA) was used to find which variables (pH, organic matter, Mehlich-III lead, EPA lead, and lettuce biomass) were most important in determining leaf lead levels. To enter the model, the significance level needed was 0.5 and to stay in the model was 0.05. Non–normal variables, Mehlich-III lead, and EPA lead, were transformed. Simple regression was then performed between leaf lead levels and biomass.

For the study of educational materials, a two-sample t-test assuming unequal variances was used to compare quiz score improvement and self-ranked learning improvement. The variable "Quiz Score Improvement" is based on participants' preprogram quiz scores subtracted from the postprogram scores when treating the five quiz questions as a single score (5=100% correct). The variable "Self-ranked Learning Improvement" is the mean of participants' postprogram responses to three questions instructing them to rank their level of knowledge (1=None, 2=Beginner, 3=Knowledgeable, 4=Expert) regarding soil testing, quality, and contamination subtracted from their preprogram responses.

Results and Discussion

Garden Profiles

Soil quality profiles of the gardens are shown in table 2. Garden size, current use, and history vary widely. Five gardens used raised beds only for food growing, three only grew food in non–raised-bed areas, and two had both raised-bed and non–raised-bed food-growing areas. Gardens were counted as raised beds if the bed was contained within a frame or consisted of compost in mounds on blacktop. The pH and fertility variables in this chart are the means for food-growing areas only in the gardens. The pH in all garden sites was appropriate. The Cooperative Extension System recommends a pH of 6.0 to 7.0 for vegetable gardens (2008), but a pH above 7.0 may be preferable in urban areas. At a higher pH, lead is less soluble and thus less available to plants for uptake (Martínez & Motto, 2000).

Our findings of very high nutrient levels in the gardens underscore the importance of soil testing, which volunteers or staff at the gardens do not currently do; only one site had been previously tested for fertility. Several garden sites contained excessive amounts of phosphorus (more than 100 parts per million), raising concerns about excessive fertilization that can pollute or limit plant productivity.

Because phosphorus level was determined through Mehlich-III, soil alkalinity was less likely to have caused an underestimation of phosphorus. In alkaline, calcareous soils, the acid in the Bray test[2] can be neutralized (Ebeling, Bundy, Kittell, & Ebeling, 2008). Potassium levels over 150 parts per million or nitrogen levels over 120 pounds per acre

[2] A widely used test for plant-available phosphorus.

Table 2. Profiles of gardens sampled in this study

Garden number	Size	Current garden usage	Site history	Type of food-growing areas in each garden	Mean pH in food-growing areas	Mean nitrogen in food-growing areas	Mean phos-phorus in food-growing areas	Mean potassium in food-growing areas	Mean EPA lead for all areas
	sq. ft.				no unit	lbs./acre	——— parts per million ———		
1	33,750	Education, individual garden plots, market, pantry donations	Tennis and basketball courts	Raised-bed	7.4	123	209	386	35.6
2	50	Individual garden plots, market	Driveway	Non–raised-bed	7.3	117	80.3	271	449
3	180	Education, shared garden space	Park entryway	Non–raised-bed	8.1	83.1	86.4	254	135
4	7,500	Education, individual garden plots, market	Unknown	Raised-bed	7.7	121	211	686	147
5	4,500	Individual garden plots, shared garden space	Vacant house lot	Non–raised-bed	8.1	82.7	56.7	157	312
6	10,000	Individual garden plots, shared garden space	Warehouse	Raised-bed and non–raised-bed	7.8	113	287	763	93.4
7	20,000	Individual garden plots	Sanitarium	Raised-bed	7.0	126	426	354	92.9
8	1,200	Education	Paved area	Raised-bed	7.0	112	89.5	274	46.4
9	3,000	Market, shared garden space	Park turf	Raised-bed	7.4	122	120	423	34.5
10	12,300	Education, individual garden plots	Schoolyard	Raised-bed and non–raised-bed	7.6	107	177	364	88.0

are also high, and indicate that those gardens do not require additional fertilization.

The overall mean lead level reported through the EPA method for the study was 135; individual soil samples from gardens ranged from 10 parts per million (nearly nondetectable) to 889 parts per million, a level high enough to cause concern. EPA lead data reported in table 2 are the means for all samples taken at each site, including soil taken from food-growing areas and other nearby areas such as bare soil paths. Six of the 10 gardens had average soil lead levels under 100 parts per million lead, the most strict cutoff suggested for growing food safely in urban soil (table 1). The average lead level from site number two, where the soil sample with 889 parts per million was taken, and also site number five, exceed some of the lead level and gardening guidelines from table 1.

The average soil lead levels in this study were lower than in other studies that sampled soil in Chicago. Shinn, Bing-Canar, Cailas, Peneff, and Binns (2000) reported a mean value of over 2,000 parts per million lead for soil in a residential Chicago neighborhood (62 composite soil samples in a four-block residential area). Another study from the same neighborhood in Chicago found an average of 639 parts per million lead amongst 87 samples (Finster et al., 2004). A study of properties owned by the city of Chicago (57 samples from 60 sites all over the city) found an average of 395 parts per million lead (Kay, Arnold, Cannon, & Graham, 2008). Taken collectively these findings confirm that lead exposure varies spatially and suggest that averages for a region or even a neighborhood are not sufficient to inform users of an individual garden about the condition of their soil resource.

As a safety precaution for the gardeners in this study, soil was resampled in spring 2009 at the two gardens where EPA lead soil means exceeded 300 parts per million. For the resampling, surface soil (approximately zero to five centimeters) was collected. Mean soil lead, analyzed with the EPA method, was lower in the surface soils than the original samples from the root zone in both gardens. One site had a mean of 185 parts per million in the surface soil, though the original sample had a mean of 449 parts per million in the rooting zone. The other site dropped from 312 parts per million in the rooting zone to 251 parts per million in the surface soil. Lower content in the surface soil could be due to the fact that garden soils are highly mixed. While some research shows that lead accumulates in surface soil, garden soil that is regularly mixed may be an exception, as shown by Clark et al. (2008), who found established garden soil to be homogenous down to 40 cm. The frequency of disturbance and importation of cleaner materials are likely contributing factors.

Raised-beds vs. Non–Raised-beds and Soil in Nearby Areas

We examined differences between soil within food-growing areas with raised beds and without. Treatment-based differences (raised-bed, non–raised-bed, other areas) between all measured fertility variables (organic matter, nitrogen, phosphorus, potassium, pH) were considered significant at $P < 0.10$ (table 3). The soil in raised-beds contained higher amounts of organic matter and nitrogen than soils in non–raised-bed garden areas or other areas, while non–raised-bed gardens and other areas contained similar amounts of organic matter and nitrogen. The raised-bed garden areas also contained more phosphorus and potassium than non–raised-bed garden areas and

Table 3. Analysis of variance results for treatment differences (raised-beds, non–raised-beds, other areas) and means for the variables organic matter, nitrogen, phosphorus, potassium, pH

Variable	ANOVA Summary		Treatment Means†		
			Raised-bed	Non–raised-bed	Other areas
	F Value	P Value	--------- milligrams/kilogram soil ---------		
Organic Matter	3.95	0.0511	168a	58.5b	85.3b
			------------------- lbs/acre -------------------		
Estimated Nitrogen Release	5.93	0.0179	119a	97.3b	97.8b
			--------------parts per million--------------		
Phosphorus	18.0	0.0003	266a	101b	65.8c
Potassium	5.40	0.0232	480a	313ab	250b
			-------------------no unit -------------------		
pH	4.25	0.0428	7.3a	7.8b	7.7ab

† Effects are considered significant at $P < 0.10$ or less. For means, transformed variables have been back-transformed. Means followed by different letters within a single row are considered significant at $P < 0.10$ or less.

other areas. These differences were significant for each type of area regarding phosphorus, but only for raised-bed gardens and other areas for potassium. The raised-bed gardens had the lowest pH, at 7.3. This pH was significantly different from non–raised-bed gardens (pH 7.8) and other areas (pH 7.7), but non–raised-bed gardens and other areas were similar. It may seem counterintuitive to find less lead in a soil with a lower pH, but once soil pH is above 6.5 or 7 it is unlikely to be a factor in the availability of soil lead.

The raised-bed garden areas had significantly less lead as detected by the EPA method than non–raised-bed garden areas, though their mean could not be separated from non–food-growing areas (table 4). With the Mehlich-III–based estimation of lead, raised-bed and non–raised-bed garden areas were significantly different, while other areas and non–raised-bed garden areas were similar. The lower lead levels in raised beds may be due to the fact that raised beds contain more uncontaminated imported materials than non–raised-bed gardens.

The importance of soil testing is clear for long-term raised beds that could be recontaminated by dust—if that occurred, then importing uncontaminated soil would be advised. Nevertheless, using raised beds may have advantages over other techniques that attempt to remediate lead in urban gardens. Soil removal is expensive. Adding phosphorus-rich compounds to precipitate lead—converting the lead to a form that is unavailable to plants—may require adding impractical amounts of phosphorus. The amount of phosphorus needed could actually be harmful to plants (Bassuk, 1986). Soil levels of phosphorus were already very high in many of the gardens, making phosphorus addition inappropriate. The potential for phosphorus additions to increase arsenic availability is another reason that that strategy may be unwise, in gardens with arsenic also present in the soil (Codling & Dao, 2007; Cao, Ma, & Shiralipour, 2003; Peryea & Kammereck, 1997). Adding organic amendments to bind heavy metals to organic compounds may also be questionable as this can sometimes result in metals becoming more soluble (Kumpiene, Lagerkvist, & Maurice, 2008). Because raised beds have the ability to contain a large amount of uncontaminated soil or compost, we believe future research comparing a larger number of raised-bed and non–raised-bed gardens is warranted.

EPA and Mehlich-III Lead

EPA lead levels and Mehlich-III lead levels were highly correlated ($R^2=0.92$; figure 4). The Mehlich-III method may offer a less expensive alternative to using the EPA digest for the types of soil in this

Table 4. Analysis of variance results for treatment differences (raised-bed, non–raised-beds, other areas) and means for the variables EPA lead, Mehlich-III lead, aluminum, copper, and zinc in parts per million

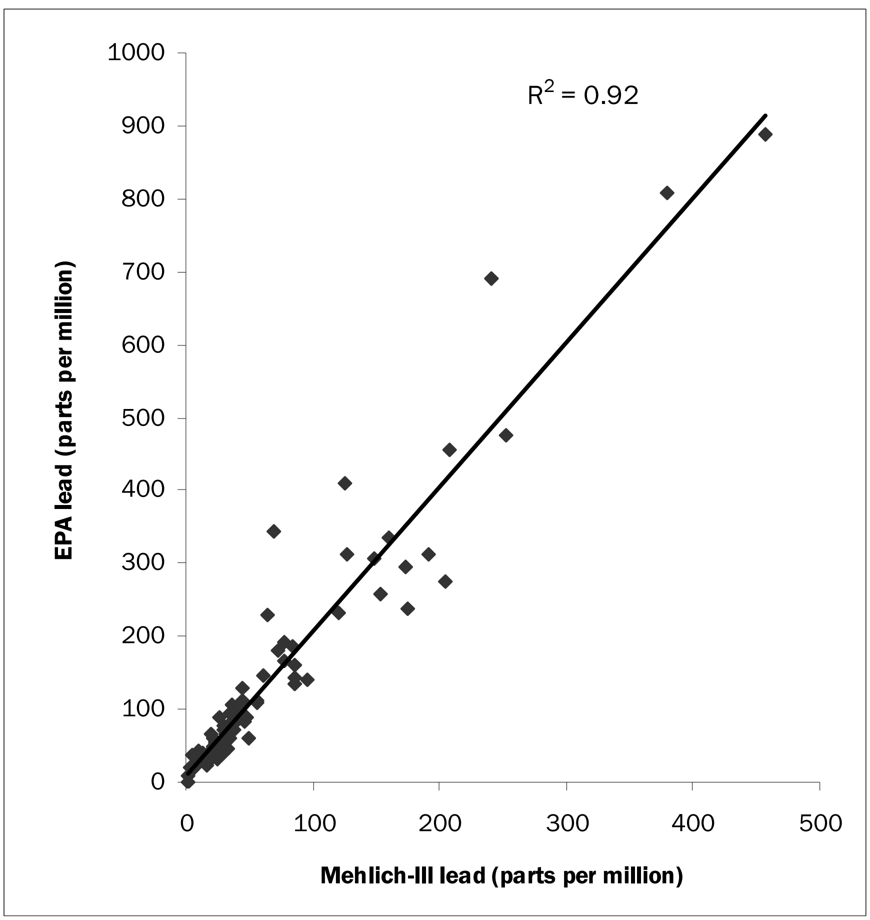
Variable	ANOVA Summary		Treatment Means†		
			Raised-bed	Non–raised-bed	Other areas
	F Value	P Value	—— parts per million ——		
EPA lead	3.70	0.0589	60.7b	224a	151ab
Mehlich-III lead	2.98	0.0923	25.5b	102a	74.7ab
Aluminum	1.70	0.230	383b	539a	502a
Copper	3.02	0.0900	8.99b	19.3a	14.5ab
Zinc	0.990	0.400	38.4	69.1	55.3

† Effects are considered significant at $P < 0.10$ or less. For means, transformed variables have been back-transformed. Means followed by different letters within a single row are considered significant at $P < 0.10$ or less.

study, mostly garden soil high in organic matter. Because Mehlich-III is a more affordable and routine procedure, its use for soil lead testing could encourage more urban gardeners to test. At Brookside Laboratories, Inc., where the soil in this study was analyzed, a single soil sample for an EPA lead test would cost $15, about three times as much as their Mehlich-III test. Soil testing prices vary widely by lab, however, and an EPA test can cost as much as $30. Some labs will not test a small number of soil samples for an individual gardener.

The high correlation to the EPA method means a simple calculation could allow gardeners to convert a Mehlich-III soil lead number to a number based on the methodology used for the EPA (and other) soil lead recommendations.

Figure 4. Correlation between EPA lead level and Mehlich-III lead level for each soil core taken



Lettuce Uptake of Lead

The highest lead concentration in the shoots (leaves plus stem) of a plant was 15.0 parts per million, and for roots was 15.2 parts per million. The mean shoot lead concentration was 7.00 parts per million and for roots was 11.8 parts per million. Finding higher concentrations in roots is consistent with other studies (Liao, Chien, Wang, Shen, & Seshaiah, 2007; Finster et al., 2004). No correlation existed between EPA or Mehlich-III soil lead and shoot lead concentrations in the lettuce, likely because individual plant uptake of metals can be complicated by factors like pH, organic matter, presence of compounds which can bind metals (like phosphates), and clay. The R^2 for Mehlich-III and shoot lead in lettuce was 0.028, and for EPA lead was 0.025. The lack of correlation is consistent with other research that failed to capture this potentially useful bioassay, including a study using Mehlich-III to predict uptake of heavy metals in beans and lettuce, which found Mehlich-III unable to predict lead uptake of lettuce (Fontes, Pereira, Neves, & Fontes, 2008). Menzies, Donn, and Kopittke (2007) reviewed literature covering extractants and metal phytoavailability and found that commonly used extractants including diethylenetriaminepentaacetic acid (DTPA), ethylenediaminetetraacetic acid (EDTA), and Mehlich-I generally poorly estimated plant availability.

The Stepwise multiple regression analysis found lettuce biomass to be the only variable among pH, organic matter, EPA lead and Mehlich-III lead to be related to leaf lead levels. Simple regression showed an R^2 of

0.75 between these two variables. When converted back to fresh weights, none of the shoots in this study exceeded the Codex Alimentarius Commission (an organization that develops food standards and is part of the World Health Organization) recommendations (CODEX, 2010), suggesting that consumption of garden produce may not be an important source of lead exposure to gardeners in this study.

Educational Materials
Fourteen of 20 people who attended the Master Gardener training completed pre- and postprogram questionnaires. After Master Gardeners were emailed an invitation to participate in the online study, 32 requested the links for the questionnaires and online module. Of those 32, 21 completed the pre- and postprogram questionnaires.

Live and online-trained Master Gardeners made significant learning gains based on quiz score improvement, and online-trained gardeners made greater gains. The quiz was worth five points total. The mean quiz score improvement for online-trained gardeners was 1.48 points and for live-trained gardeners was .710 point (results were considered significant at $P < 0.10$). In addition to answering quiz questions, participants were asked to report if they believed they made gains in their knowledge about soil testing, soil contamination, and soil quality, using a four point scale. Both groups self-reported significant gains in learning after the programs, with the online participants reporting more learning gains than the live-trained group. The mean self-reported gains in learning were 2.71 points for online-trained gardeners and 1.75 points for the live-trained group.

The demographic information for the online and live-trained Master Gardener groups (table 5) is similar to demographics of studies surveying both Master Gardeners and gardeners in general (table 6). In all cases, a greater percentage of respondents were female. Respondents were most frequently 50 years of age or older. The improvement of the Master Gardener group may be indicative of the kind of improvement gardeners in general would demonstrate after the trainings.

Table 5. Demographic information for Master Gardeners at live (n=14) and online (n=21) trainings

Variable	Live training (%)	Online training (%)
Female	71.4	89.3
Male	28.5	10.5
Age (years)		
18-25	7.00	0
26-35	7.00	0
36-49	21.0	14.3
50-64	29.0	66.7
65+	36.0	14.3
Mean length of time as a Master Gardener (years)	2.90	5.30

No significant differences in pre- and post-test scores were reported by Jeanette and Meyer (2002) between online and live-trained groups for a Master Gardener horticulture course, and both groups had significantly higher post-test scores. A study comparing a web-based and live horticulture class about plant identification found the students who received live instruction scored higher (Teolis, Peffley, & Wester, 2007). It is possible that the greater improvement of online users in our study occurred because they could spend an unlimited amount of time reviewing the material, as opposed to the live trainings, or because they took advantage of links sending them to more detailed information.

We also explored whether offering live and online training was duplicative or reached different groups of gardeners. Regarding learning preferences, the online learners in our study most often listed the Internet as a favorite way to learn something new (75%), while this option was one of the least often chosen for the live-trained group (43%). The most frequent option chosen for the live-trained group was hands-on activities (79%), followed by listening to a lecture. Listening to a lecture was the least-

Table 6. Summary of demographic information for Master Gardeners and gardeners in general

Reference	Subject	Location	n	Age (%)	Gender (%)	Married (%)
			# of people			
Meyer & Foord, 2008	Gardeners	Minnesota	523	Under 50 39.0 Over 50 61.0	Female 78.0 Male 22.0	
			# of households			
Standard Rate & Data Service, 2004	Vegetable gardeners	U.S.	26,593,946[a]	18 to 24 1.70 25 to 34 10.0 35 to 44 20.2 45 to 54 23.9 55 to 64 18.7 65 to 74 13.9 75 and over 11.6	Female (single) 19.6 Male (single) 12.7	67.7
			# of people			
VanDerZanden & Kirsch, 2003	Master Gardeners	Oregon	132	51 or less 31.0 52 or more 69.0	Female 74.0 Male 26.0	
Finch, 1997	Master Gardeners	Bexar County, Texas	248	Under 25 3.00 25 to 34 17.0 35 to 44 33.0 45 to 54 20.0 55 to 64 17.0 65 to 74 9.00 75 and over 2.00	Female 56.0 Male 44.0	
			# of households			
National Gardening Association, 1996	Vegetable gardeners	U.S.	28,000,000[a]	18 to 29 19.0 30 to 49 44.3 50 and over 37.9	Female 56.0 Male 44.6	64.0
			# of people			
Rohs & Westerfield, 1996	Master Gardeners	Atlanta area	77	Under 25 5.00 25 to 50 40.0 Over 50 55.0	Female 69.0 Male 31.0	84.0

[a] These figures are adjusted to represent the U.S. as a whole.

often option chosen by the online group (35%). This suggests the importance of offering materials in both live and online formats to accommodate two distinct sets of preferences. It also suggests that participants may have been predisposed to certain types of learning. Additionally, these preferences are likely due to learning style and not because of lack of Internet access. No one from either group said they never use the Internet, and more than 90% of both the online and live-trained groups said they most often use the Internet at home, as opposed to work, the library, or other. High percentages of respondents (80% of the online group and 79% of the live group) said a new website about urban soil quality would be useful to them. Respondents in the Meyer and Foord (2008) study about how consumers access gardening information reported that they learned gardening information the best from friends or others (75%), and only 28% identified the Internet as the best learning tool. Expression of a stronger preference for online learning by the live-trained group in our study, as compared to Meyer and Foord, could be because they were asked their favorite way to learn something new as a general statement, not specifically about gardening.

All the online respondents were able to access the video clips. VanDerZanden and Hilgert (2002) found that Master Gardeners surveyed after using an online training module could not access videos, decreasing user satisfaction. Participants in our study may have had easier access to videos because the videos were hosted on a video-sharing website with minimum computer requirements to view the videos (computers needed Adobe Flash Player and to have JavaScript enabled). Advances in free, user-friendly technology may play an important part in enhancing accessibility to online materials. Finally, users left various additional comments, most notably, three objected to the word lead being written as "Pb,"" underscoring the need to communicate with plain language.

Conclusion

Urban gardeners need to know their soil, and to do this they need more access to information about soil testing. In this study, soil in raised-bed garden areas contained less lead and more nutrients than soil in garden areas not using raised beds and soil in nearby areas. The lack of soil testing among the 10 gardens in this study is likely a contributing factor to the overfertilization of the gardens. The overall mean total lead level reported through the EPA method for the study was 135 parts per million. Six of the 10 gardens had mean soil lead levels under 100 parts per million lead, the most stringent cutoff suggested for growing food in urban soil (table 1). The average soil lead levels in this study were lower than in other studies sampling in Chicago. The majority of soil lead levels in this study do not cause concern. For gardens containing low amounts of lead, soil testing could reassure gardeners overwhelmed by the various techniques to avoid or reduce soil lead exposure (table 7), some of which are expensive or time-consuming. We believe that future study involving a greater number of gardens should investigate further the potential of raised beds to mitigate lead levels and the possibility of recontamination from exposed soil in nearby garden areas.

A standard interpretation for lead levels in garden soil that accounts for lead ingested through produce is needed, along with potential for recontamination from nearby soil, soil pH, and other factors. A standard approach to sampling garden soils is also needed. We encourage sampling from the root zone in food-growing areas (and surface sampling in other key areas) to allow gardeners to use some samples for the dual purposes of environmental and nutrient analysis while still minding the possible threat of lead accumulation on surface soil.

Total lead levels and Mehlich-III lead levels were highly correlated. We believe future study investigating the relationship between reported EPA and Mehlich-III lead levels could lead to the development of a soil lead assay that most soil-testing laboratories could do inexpensively and easily for gardeners with small numbers of samples.

Live and online-trained Master Gardeners made significant learning gains based on quiz score improvement, and online-trained gardeners made greater gains. The mean quiz score improvement for online-trained gardeners was 1.48 points and for live-trained gardeners was .710 point. Both groups self-reported significant gains in learning after the programs, with the online participants self-reporting more learning gains than the live-trained group. The mean self-reported gains in learning were 2.71 points for the online-trained group and 1.75 points for the live-trained group. It is possible that the greater improvement of online users in our study occurred because they could spend an unlimited amount of time reviewing the material, as opposed to the live trainings, or because they took advantage of links sending them to more detailed information.

The development of protocols for sampling in urban gardens, ways to interpret those results, and better tools for understanding this information would benefit urban gardeners greatly. We suggest further development of online resources about urban soil quality to deliver content to urban gardeners.

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Table 7. Suggested practices for gardeners to avoid or reduce lead exposure while gardening food crops†

Practice	Source(s)
Survey the property for potential lead hazards.	Finster et al., 2004
Garden away from busy streets and old buildings to reduce soil dust deposits.	Angima & Sullivan, 2008; Finster et al., 2004; Rosen, 2002; Stehouwer & Macneal, 1999; Logan, 1993;
Cover bare soil with mulch or other materials to reduce soil dust deposits.	Angima & Sullivan, 2008; Stilwell et al., 2008; Finster et al., 2004; Rosen, 2002; Peryea, 1999; Stehouwer & Macneal, 1999; Logan, 1993;
Moisten soil when gardening to reduce airborne dust.	Peryea, 1999
Erect a fence or hedge to reduce air-born dust from streets or known contaminated areas.	Stehouwer, 1999; Logan, 1993
Wash hands after gardening to reduce ingestion of soil.	Stilwell et al., 2008; Peryea, 1999; Stehouwer & Macneal, 1999; Logan, 1993
Use disposable gloves to reduce soil ingestion.	Peryea, 1999
Avoid touching your mouth while gardening by not smoking or eating to reduce ingestion of soil.	Peryea, 1999
Wear a dust mask to reduce soil ingestion.	Peryea, 1999
Shower after gardening to remove soil.	Peryea, 1999
Wash garden tools outside.	Peryea, 1999
Store designated gardening clothes outside.	Peryea, 1999
Wash garden clothes outside by hand or in a separate load.	Peryea, 1999
Wash garden produce (some recommend using dilute vinegar) to reduce soil ingestion.	Angima & Sullivan, 2008; Stilwell et al., 2008; Finster et al., 2004; Rosen, 2002; Peryea, 1999; Stehouwer & Macneal, 1999; Logan, 1993
Remove outer leaves of leafy crops, peel root crops, and do not compost these materials.	Rosen, 2002; Logan, 1993
Do not compost plants grown in contaminated soil.	Finster et al., 2004
Avoid growing leafy greens or root crops.	Angima & Sullivan, 2008; Stilwell et al., 2008; Finster et al., 2004; Stehouwer & Macneal, 1999; Logan, 1993
Soil test for lead and other factors that may affect the availability of lead in the soil, including pH.	Angima & Sullivan, 2008; Finster et al., 2004; Rosen, 2002; Logan, 1993
Keep soil pH above 6.5 or 7 to reduce lead availability.	Angima & Sullivan, 2008; Stilwell et al., 2008; Finster et al,, 2004; Rosen, 2002; Peryea, 1999; Stehouwer & Macneal, 1999; Logan, 1993
Amend soil with organic matter and/or phosphorus to reduce lead availability.	Angima & Sullivan, 2008; Stilwell et al., 2008; Finster et al., 2004; Rosen, 2002; Peryea, 1999; Stehouwer & Macneal, 1999; Logan, 1993
Use raised beds or containers filled with uncontaminated materials.	Angima & Sullivan, 2008; Chicago Park District, 2008; Stilwell et al., 2008; Finster et al., 2004; Peryea, 1999; Stehouwer & Macneal, 1999; Logan, 1993
Remove the top three to five centimeters of soil in raised beds and replace it with compost each year.	Clark et al., 2008
Use barriers such as landscape fabric or plastic sheeting between the original site soil and added uncontaminated soil/compost.	Angima & Sullivan, 2008; Chicago Park District, 2008; Stilwell et al., 2008; Finster et al,, 2004; Peryea, 1999
Replace contaminated soil with uncontaminated soil.	Angima & Sullivan, 2008; Peryea 1999
Screen children for a blood lead level test.	Rosen, 2002; Logan, 1993

† Some sources recommend certain practices in response to particular soil test results.

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