Addressing Community Concerns about Lead Contamination in Soil: Insights for Site Cleanup - 8307

M.E. Finster
Argonne National Laboratory, Environmental Science Division
9700 S. Cass Avenue, Argonne, IL 60439

ABSTRACT

Health risks associated with contaminated sites are a key driver for cleanup decisions and determinations about alternate land use of areas released to the public, particularly in heavily populated metropolitan areas. To guide risk management and future use decisions at contaminated sites, insights can be gained from community-based research. These evaluations can also help ensure that assessments and decisions developed for urban sites consider input received from community members.

In order to evaluate the potential risk due to consumption of plants homegrown in lead-contaminated soil, a pilot study was conducted over a period of two summers in a Chicago, IL neighborhood. This survey included analyses of lead concentrations in a convenience sampling of edible fruits, vegetables, and herbs and also examined how the sample preparation method affected the lead concentrations detected in plant materials.

A pattern of lead transfer from soil through the root to the stem and leaves of garden crops was found. This pattern is a concern particularly for plants in which the roots, stems, stalks, or leaves are consumed. Analyses of fruiting vegetables indicated that concentrations were below the limit of detection. Depending on the soil lead level and specific plant, the contamination found in some leafy vegetables and herbs may exceed the body's daily excretion rate and could contribute to the total body burden of lead, especially in children. Finally, washing edible portions did not necessarily eliminate the risk, indicating that the lead was located both on and in the plant tissue.

This research was conducted in coordination with health experts from the community, and local citizens were involved in discussions on the research and implications for their health protection measures. In certain residential locations, identifying and understanding the potential source of lead contamination provides information for the community such that simple measures can be applied for protecting their health (e.g., creating a raised bed, or relocating garden areas). Similar practical measures can be applied for more complex sites, to frame land use decisions in a way that can account for localized hot spots without precluding all options of interest to projected future users.

INTRODUCTION

Lead is common environmental soil contaminant, which does not dissipate, biodegrade, or decay, and it is a common constituent at contaminated sites. Lead is a neurotoxic heavy metal that may accumulate in the human body, although it has no biological value. It is highly toxic because when ingested or inhaled and absorbed, it can harm virtually every system in the human body, especially the brain, kidney and reproductive systems of both males and females. Children, infants and fetuses are at particularly high risk for lead's neurotoxic and developmental effects.

Lead is widely distributed and ubiquitous in the urban environment due to heavy traffic patterns, past use of leaded gasoline, a high concentration of industry, and an older housing stock with lead-containing paint. In addition, soil that has been contaminated with lead often looks identical to soil that is free of such contamination, and its capacity to support lush plant growth offers little indication of the lurking contamination [1]. In recent years, urban and community gardening has become increasingly popular in nearly all socioeconomic groups in the United States [2, 3], particularly with respect to use or re-use of vacant land located within residential neighborhoods. Thus, urban soils with extreme lead contamination are not only a huge environmental problem, but a pressing public health concern as well.

The ingestion of lead from fruits and vegetables grown in the home environment is a potential route of exposure that has received little attention, but may prove to be a recurring source of lead for both children and adults [4, 5]. Fruits and vegetables grown in contaminated soil may become contaminated as a result of plant uptake of lead from soils or direct deposition of leaded dust onto plant surfaces [6, 7]. Therefore, through these diverse mechanisms, lead deposited into soil becomes a persistent and long-term source of lead exposure for humans, particularly children.

Although it is known that all plants can accumulate lead to some extent, minimal investigation has been conducted on the relationship between soil lead levels and lead concentrations found in edible plants, or on the tendency of typical urban garden plants to translocate lead. Thus, health effects associated with lead contaminated soil is of concern as an ingestion threat to the general public, especially urban gardeners. The occurrence of lead in the edible portion of the plant is of specific interest from a health point of view, since ingestion of the plant may contribute to elevated body burdens of lead, and the gardening scenario is also a common component of baseline risk assessments for contaminated sites.

This pilot study investigated the relationship between lead concentrations in urban garden soils and crops grown in these soils, particularly the levels of lead detected in the edible portions of the plant. In addition, this study examined how the sample preparation method effected the lead concentrations detected in the plant. Data are needed to evaluate the potential health hazard due to the consumption of plants homegrown in gardens with lead-contaminated soil, guide the development of safety recommendations for urban gardening enthusiasts, and ensure that assessments and decisions developed for urban sites consider impact on the community members. This survey included analyses of lead concentration in a convenience sampling of edible fruits, vegetables, and herbs and was conducted over a period of two summers in one Chicago neighborhood.

METHODS

The field survey occurred within the West Town neighborhood of Chicago in the late summer of 2000 and 2001. The homes and apartments in the area are a mixture of brick, stone, and wood frame exteriors. Age of construction for all homes on the properties included in the study was obtained from tax records [8] and reveal that all homes were built before 1900 (range 1872-1899). Major roads bordered the study blocks on two sides, with minor roads along the other two sides. Prior research at the properties on the two residential streets in the south area found soil lead levels to be in the range of 175-7953 ppm [9], with median values of 2289 ppm and 1263 ppm.

For the purposes of this study, a visual tour of all properties was conducted in order to identify gardens and plant varieties to be sampled. Permission of the property owner and gardener (if different from owner) was obtained prior to sampling, and results were provided at the completion of the study. One plant of each variety was sampled from the assessed properties; thus, the number and type of plant samples obtained reflects their relative abundance and frequency of occurrence in the neighborhood. The plant samples were harvested near the end of two growing seasons (September 2000 and 2001). The species collected represent those selected by the gardeners and grown for their own enjoyment or consumption. The varieties of plant types collected and tested are listed in Table I [1].

Table I. Plant Types Collected [1]

Fruiting edibles		**Leafy edibles**		**Root edibles**	
Plant	***n***	***Plant***	***n***	***Plant***	***n***
Apple	2	Basil	1	Carrot	1
Bean, Green	2	Cabbage	3	Onion	1
Cantaloupe	1	Cilantro	1	Radish	2
Corn	2	Collard Greens	1		
Cucumber	7	Coriander	1		
Grapes	4	Ipasote	1		
Peppers, Bell	7	Lemon Balm	1		
Peppers, Hot	10	Mint	9		
Strawberries	4	Mustard Greens	1		
Squash, Acorn	1	Parsley	2		
Squash, Butternut	1	Red Chard	1		
Tomato	9	Rhubarb, Green	2		
Watermelon	1	Rhubarb, Red	2		
Zucchini	1	Sage	2		
		Swiss Chard	2		
		Thyme	1		

During the first year, the entire plant was harvested and separated into sections including root (underground portion), shoot (above ground portion, including stem and leaves), and edible fruit, so to understand where they accumulated and stored lead and where potential exposure hazards might exist. In the second year, only samples of edible portions of the plants were taken, which included edible fruits, shoots of leafy vegetables and herbs, and roots of rooting vegetables. In addition, it should be noted that only one of each sample type (root, shoot, or edible) was obtained and analyzed from each plant. In both years for each plant sampled, a corresponding soil sample was taken at the time of harvest. Soil samples were collected by obtaining 4 to 6 sub samples of the surface soil (corresponding to a depth of 0 to 3 inches) in the 1-foot area surrounding the plant. The soil samples corresponding to each plant were homogenized and analyzed as a composite sample.

To ensure that the measurements of lead in homegrown plants reflect the expected exposure concentrations as closely as possible, measurements were made on vegetables after they had been prepared for consumption. Therefore, the samples of harvested garden plants were prepared in two ways: rinsed in tap water or washed with a mild detergent solution. The measurements made of the water-rinsed samples reflected a combination of lead deposited on the plant surface and incorporated into the plant, whereas those taken of the plant samples washed with the mild detergent to remove adhered soil represented only the lead incorporated into the actual plant tissue.

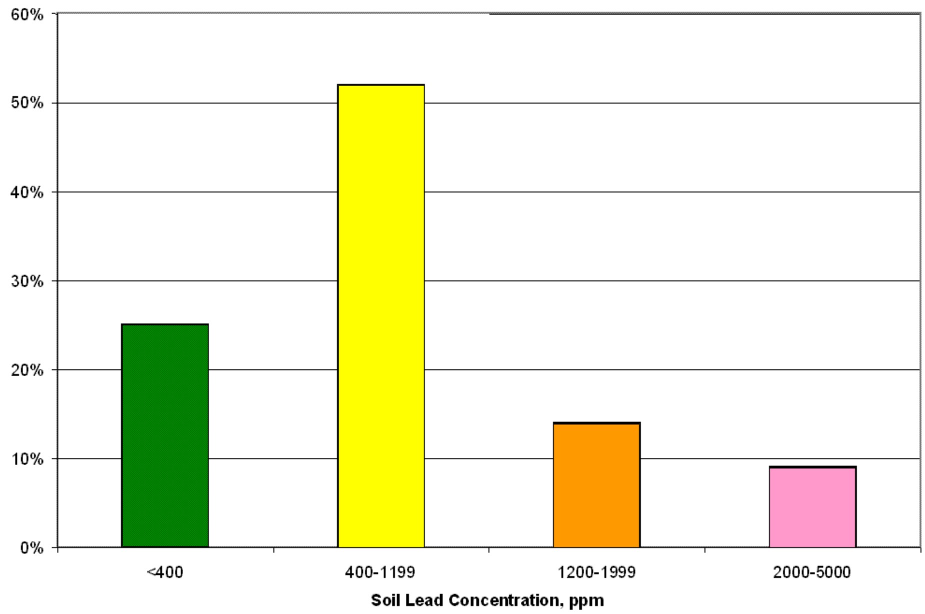
After washing, both plants and soils were then dried and digested using SW 846 EPA Method 3050 [10]. The various sections of the plants were analyzed for lead content using Inductively Coupled Plasma - Atomic Emission Spectrometry (ICP-AES), having a detection limit of 10 ppm (microgram lead per gram dry plant matter). This detection limit was set using the EPA method found in 40 CFR Part 136, Appendix B [11]. Soils were analyzed using Flame Atomic Absorbance (FAA) analysis with a detection limit of 60 ppm. For the few soil samples having lead levels less than the detection limit, an estimated laboratory value was used in the statistical analyses. In addition, seven samples of lead free soil were identically spiked at a concentration of approximately five times the detection limit and analyzed.

RESULTS

Samples and Soil Lead

Garden produce samples (n=87) were obtained from the 17 properties. A range of 1 to 29 plants was sampled per property (10 properties had 1 or 2 plants sampled, 5 properties had 3-8, and 2 had >10). Soil lead concentration associated with each plant varied from 27 to 4580 ppm (median 800 ppm, geometric mean 639 ppm), with the maximum difference between highest and lowest soil samples of 3687 ppm within a property [1].

Figure 1. Distribution of Soil Lead Concentration (n=87)



Plants

For the purposes of analysis, the samples were pooled across species and separated into three different groups based upon plant type (i.e. fruit and fruiting vegetables, leafy vegetables and herbs, and root vegetables). The data for the samples that were found to have a detectable level of lead in the edible portion are summarized in Table II.

The results revealed that only one fruiting vegetable (cucumber at 81 ppm), among the 52 sampled, was found to have a detectable lead concentration in the edible portion. That one fruiting vegetable had been rinsed with water only. However, the data indicate that 39% (12 of 31) of the leafy vegetables and herbs sampled showed lead in edible shoot portions, where detergent washing did not necessarily eliminate lead (50% [8/16] of water-washed leafy edibles and 28% [4/15] of detergent-washed samples showed lead detection). In addition, although only 4 root vegetables were sampled, all of those analyzed exhibited detectable lead concentration in the edible section (or adhered to the edible section, since 3 of 4 were water-washed).

Table II. Edible Samples with Detectable Lead Levels

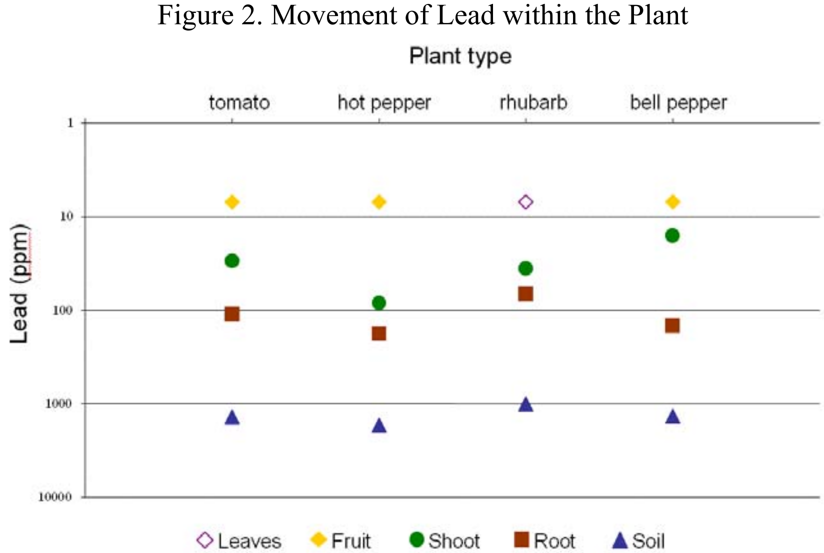
Plant type	Preparation Technique	Lead Concentration[a]			
		Soil (ppm)	Root[b] (µg/g)	Shoot[b] (µg/g)	Edible[b] (µg/g)
Fruit and Fruiting Vegetables					
Cucumber	water	1280	396	125	81
Leafy Vegetables and Herbs					
Cilantro	water	2110	79	49	NA
Collard Greens	water	4580	201	12	NA
Corriander	water	982	141	39	NA
Ipasote	detergent	550	-	14	NA
Lemon Balm	water	1110	420	20	NA
Mint	water	847	161	11	NA
Mint	water	2270	592	60	NA
Mint	detergent	920	-	15	NA
Mint	detergent	2300	-	12	NA
Rhubarb, Green	water	1010	68	36	NA
Swiss Chard	water	902	112	22	NA
Swiss Chard	detergent	910	-	24	NA
Root Vegetables					
Carrot	water	1890	10	<10	NA
Onion	water	616	21	<10	NA
Radish	water	533	12	<10	NA
Radish	detergent	960	18	-	NA

[a] The dash '-' indicates that a sample of this type was not taken. NA denotes the type is "Not Applicable".
[b] Plant sample concentrations are presented in micrograms of lead per gram of dry plant matter.

Concentration of Lead throughout the Plant

The relationship between soil lead concentration and the concentration of lead in the root and the above ground portions of the plants was further examined. In nearly all of the plants analyzed, the root portion of the plant showed the highest levels of lead, followed by the shoot and then the leaves. For illustrative purpose, Figure 2 shows this phenomenon, the proximal to distal transference of lead, for a tomato, hot pepper, rhubarb, and bell pepper plant, which were collected in 2000, during the first summer of this study [1]. These samples were all subjected to water wash only.

Figure 2. Movement of Lead within the Plant



Relationship of Lead in Roots, Shoots and Edibles to Soil Lead Concentration

Among fruiting and leafy edibles, considering the root and soil lead results (n=41), there was a significant correlation between root and soil lead. These root samples were all prepared by water wash only. No comparable samples of detergent washed roots were prepared and analyzed. The data illustrated in Figure 3 display the root lead concentration verses the soil lead concentration [1]. In an analysis of variance model, soil lead concentration accounted for a majority of the variation in root lead concentration. Root lead concentration had a median value of 12% of soil lead concentration (range 3% to 51%).

Figure 3. Relationship of Root Lead and Soil Lead

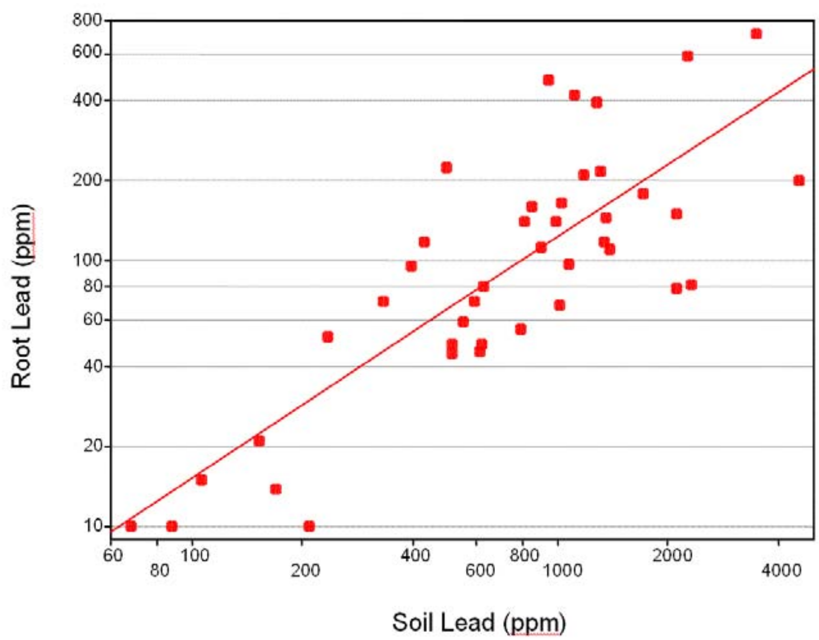


Figure 4, on the next page, shows the relationship of shoot and soil lead concentration, labeled by wash method and plant type, for the 56 fruiting and leafy plants [1]. No shoots of the fruiting plants underwent detergent wash. Note the four fold scale difference between root lead and shoot lead figures. Among samples with detectable lead in the shoot (n=22), shoot lead concentration was an average of 27% of root lead concentration (range 3% to 72%), while the shoot had a median value of 2% of soil lead (range 0.2% to 10%). Among the shoots tested, there was only 1 of 13 samples with detectable shoot lead and a soil lead result less than the U.S. Regulatory soil lead hazard standard of 400 ppm, while 42% (18/43) of shoot samples grown at a soil lead of 400 ppm or higher had detectable shoot lead. It is important to note, however, that in the case of the single shoot sample with detectable lead grown in soil having lead levels below the 400 ppm hazard cut off, the soil lead levelwas 399 ppm, a value very close to the regulatory limit.

Detectable lead concentrations in the edible fruit, vegetable, and herb samples, ranged from 11 to 81 µg/g, as illustrated in Figure 5, on the next page [1]. No significant relationship was found between lead content of the edible and soil lead concentration.

Figure 4. Relationship of Soil Lead and Lead Content of the Shoot by Washing Method

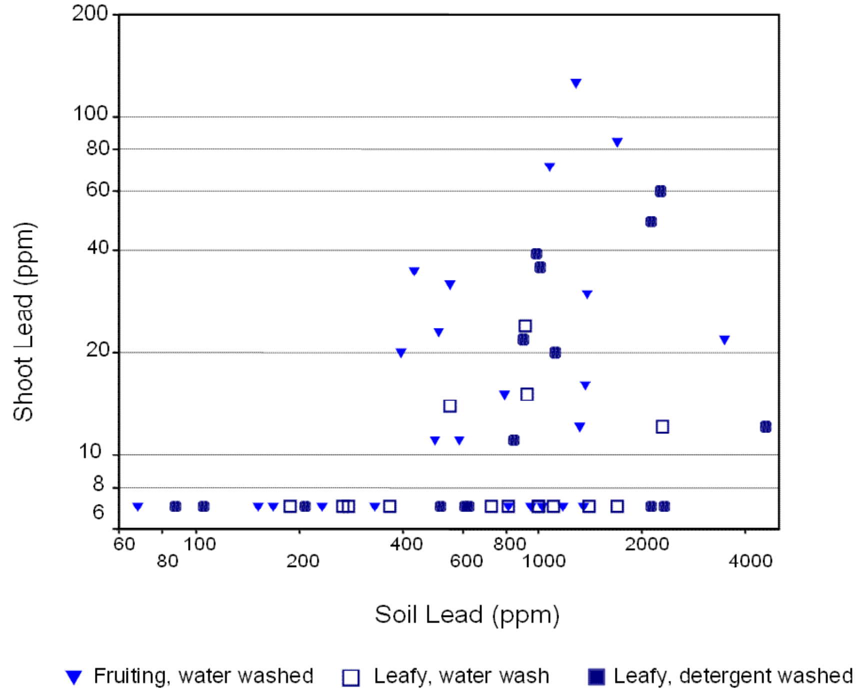
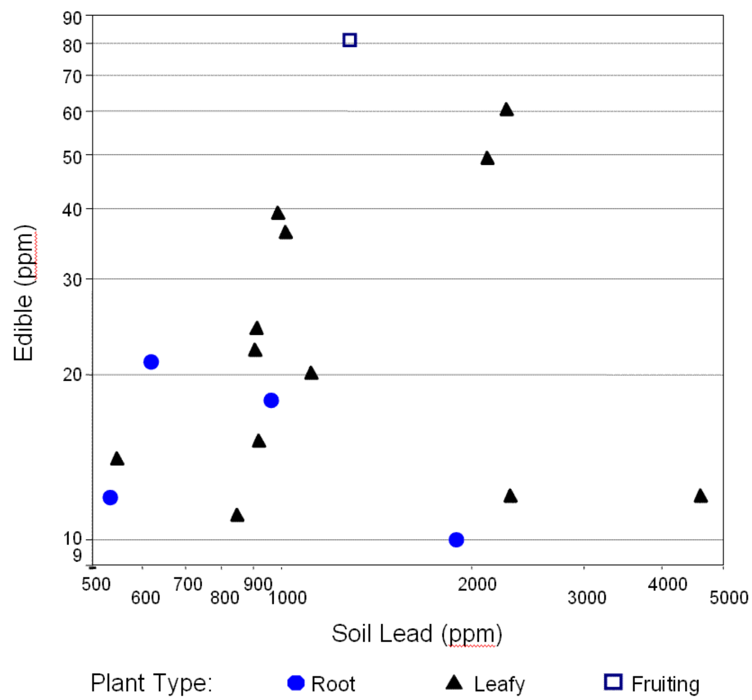


Figure 5. Edible Plant Portions and Soil Lead Relationship



DISCUSSION

This urban-based screening study demonstrated that all garden vegetable plants grown in a contaminated soil accumulate lead to some level [1]. There exists a strong relationship between soil lead and root lead concentration and less predictable relationships between soil and shoot lead or lead in the edible portions of plants. The concentration pattern observed throughout the plant revealed that lead was primarily localized in the root portion of the plants, followed by a decreasing gradient of concentration up the plant shoot, and low to non-detectable concentration in the edible fruiting parts. The data support potential translocation of lead from the root into the shoot, although some of the values may be enhanced due to the presence of surface adhered soil. Transference of lead to the fruiting portions of the plant, if present, was at levels below the experimental limit of detection. This trend suggests that, in general, the root portion of most plants is likely to be associated with the greatest potential hazard if consumed.

A look at these pilot data leads to the conclusion that lead absorption does not concentrate in the edible parts of fruit and fruiting vegetable plants (e.g., tomatoes, peppers, beans, zucchini), assuming they are washed thoroughly to remove any surface adhered soil. The only edible sample, a cucumber, with an experimentally detectable lead concentration (81 ppm) was only rinsed with tap water before analysis. Thus, it is presumed that surface adherence of lead may persist following water washing, so this may be an additional problem for fruits, that otherwise would be safe [1].

Plants with edible leafy vegetables (e.g., collard greens, Swiss chard), herbs (e.g., cilantro, mint), and edible roots (e.g., carrot, radish, onion), were found to have the highest levels of lead. Others have found similar levels of lead in leafy vegetables [6, 12]. The four root vegetables, which were tested in this study, all showed a detectable amount of lead in the edible root. While the low number of root edibles sampled is a study limitation, others have found a similar pattern for lead accumulation [6, 13, 14]. These data indicate that the risk from lead for leafy and root edibles is a result of both lead contaminated dust attached to the plant surface and direct uptake of lead into the plant tissue, since detectable lead concentrations were measured for both types of sample preparation techniques. Thus, washing edible shoot and root plants with a mild detergent solution will only help remove the risk associated with the lead contaminated soil adhering to the plant surface; it will not affect the lead that has become incorporated within the plant tissue through direct uptake. Although twice as many water-only washed samples had detectable lead, no significant difference was found in the lead content of leafy edibles for water-only washed versus detergent-washed samples. Thus, the power to detect a difference was limited. Detergent washing of edibles grown in urban soils is, nonetheless, recommended [1].

Gardens are not usually regarded as potentially dangerous or toxic areas within a residential property; however, the majority (greater than 75%) of urban garden soil samples tested were contaminated with levels of lead above 400 ppm, the level declared safe for child play [15]. Although some research indicates that soil ingestion, which is primarily due to a child's hand to mouth activity [16], allows much greater lead exposure than the consumption of garden vegetables grown in the contaminated soil [17], these data suggest that an additional hazard associated with eating plants grown in urban gardens does exist [1].

Health Consequences of Lead in Edibles

The contribution of garden vegetables to lead ingestion depends on several factors including the percentage of the diet made up of lead-laden homegrown vegetables and the type of vegetable preparation (e.g., washing, peeling). Additionally, after lead is ingested, it can only adversely affect health if it is absorbed. Adults absorb approximately 11% of ingested lead [18], and excrete approximately 50-60% of that ingested over the short term (at a half-life of approximately 20 days) and an additional 25% over many months, with the excretion rate dependent on the total body burden of lead [19]. The residual lead accumulates in mineralizing tissues (i.e., bones and teeth). Children, on the other hand, can absorb anywhere from 30-75% of ingested lead [18] and an infant can excrete only approximately 5 μg/kg/day [20]. Accumulation of lead in women of childbearing age is problematic, as transfer of lead to the fetus can occur, and lead stored in bone is mobilized during pregnancy (hence, made available to transfer to the fetus) [21], particularly with low dietary calcium intake [22]. As a result, the consumption of lead contaminated root crops, leafy vegetables, and herbs may contribute to the total body burden of lead with variable amounts of lead retained in the body over many years.

Diets laden with urban-grown herbs may substantially contribute to a person's lead burden. For example, if a person were to consume as little as 1 tablespoon of dried cilantro (weighing approximately 1.75 grams), with a lead concentration of 49 micrograms of lead per gram dry weight of sample, they would be ingesting approximately 86 μg of lead [1]. As a result, this value would contribute to their total body burden of lead, for it exceeds the U.S. FDA's recommended Provisional Total Tolerable Intake Levels (PTTIL) for all age groups, which are defined at 6 μg lead/day for children up to 6 years of age, 15 μg lead/day for children 7 years and older, 25 μg lead/day for pregnant woman, and 75 μg lead/day for other adults [23]. In contrast, the total daily lead in the diet of a pre-industrialized child has been estimated at 0.68 μg lead/day, which is a small fraction of the amount found in many of the leafy plants in this study [24].

A study of the diets of children residing in lead-laden environments found the average total dietary intake to be 8.37 μg lead/day, with mean dietary intake of lead at 29.2 μg lead/day attributed to additional contamination of food due to handling [25]. In turn, corresponding blood lead levels (BBL) of 6.9 and 8.3 μg/dl, respectively, were calculated from regression equations generated by the USEPA's Integrated Exposure Uptake Biokinetics Model (IEUBK) using the study data [25]. Thus, utilizing the same predictive approach, the estimated ingestion value of 86 μg, if added to the average total and mean dietary intake levels and used in the same correlation equations to estimate corresponding BBLs, would result in levels around 9.9 and 10.2 μg/dl, respectively [1]. These resulting BLLs are of concern with respect to the health of a child since they bring the lead level up to the toxic blood lead levels of 10 μg /dl, as defined the Centers for Disease Control and Prevention (CDC).

Recommendations for Urban Gardeners

Because urban gardening is a wide spread activity with potential health impacts, it is imperative that people be equipped with the information and knowledge necessary to reduce or eliminate the potential risks associated with urban gardening. Table III, on the following page, lists recommendations urban gardeners may elect to follow so to lower risks associated with gardening [1]. The first step is a survey of the property. Based on research of urban soil lead contamination, it is recommend that urban gardeners only consider fruit and vegetable gardening in areas away from older building foundations, which have highest levels of soil lead contamination within a property [26]. Once an area for gardening has been determined, the next important step in evaluating potential lead hazards is to test a soil for its lead concentration. Due to the fact that there exists a wide variation in soil lead concentration within vegetable garden areas of a single property, as illustrated in this study, soil samples should be taken from all areas where gardening is planned and tested separately to ensure a comprehensive understanding of where potential lead hazards exist.

The risk of gardening in lead contaminated soil is both from the lead contamination of the edibles and the practices that might promote ingestion of lead contaminated soil (e.g., oral behaviors, soil track-in to the home). While there are no federal standards or guidelines for soil lead concentration for home gardening, it is recommend that all food crops should be grown in a soil in which the lead concentration is less that 400 ppm, the current U.S regulatory soil hazard standard that is considered safe for child play [15]. This soil exposure limit is supported by the data in this study. However, the gardener should recognize that any regulatory cutoff point does not ensure safety and keep in mind that background soil lead contamination levels are less than one-tenth this suggested 400 ppm soil hazard level [27].

Table III. Recommendations for Urban Gardeners

- Survey the property to determine the potential lead hazards, extent of the contamination, and location of high-risk areas.
- Plan to locate fruit and vegetable gardens away from buildings, especially if peeling paint is evident, and sites where sludge with heavy metals was applied.
- Analyze lead concentration in soil samples from areas where vegetable gardens exist or are planned.
- Do not grow food crops in a soil that is contaminated to levels greater than 400 ppm.
- Instead, use either containers or construct raised beds, with a semi-permeable barrier between the clean and contaminated soil.
- Where container or raised bed gardening is not possible, fruiting crops should be grown.
- Root vegetables, leafy greens, and herbs should not be planted in contaminated soils.
- Test new topsoil before using it and annually retest the garden soil to monitor for recontamination.
- Do not use plants grown in contaminated soils for compost.
- Use mulch or a weed tarp in garden beds to reduce the potential for aerial soil dust deposition or soil splash up on crops.

The urban vegetable gardener is encouraged to either use containers or construct raised beds for gardening, particularly for root vegetables, leafy greens, and herbs, which can accumulate lead in their edible tissues. New topsoil, with proven low lead contamination, should be used to fill the containers and raised beds, and a semi-permeable barrier, which allows water transmission, should be placed between the clean and contaminated soil. Retesting the new garden soil for lead is an essential way to monitor for recontamination, particularly if there was an event that might have resulted in soil lead contamination. This is necessary even in residential yards that have been cleared of lead hazards, since recontamination may occur as a result of a neighbor’s lead problem, such as deteriorated lead-based paint or unsafe renovation or construction procedures (e.g., sanding or scrapping of lead-based paint) that may transmit lead widely within a neighborhood [9, 28]. Where container or raised bed gardening is not possible, fruiting crops should be grown, for they were found to have non-detectable amounts of lead in their edible parts. Additional barriers to lead accumulation in garden plants, subsequent to any lead recontamination, may be created by using organic compost high in phosphate and maintaining alkaline soil conditions ($pH>7$), which are reported to reduce lead mobility in the soil [12]. Furthermore, the use of mulch or a weed tarp in the garden bed can reduce the potential for aerial soil dust deposition or soil splash up on crops.

Moreover, it is important that plants grown in contaminated soils are not used for compost, for this would result in lead recycling within a garden since most plants were shown to accumulate lead to some extent, particularly within their roots. Due to concern about directly ingesting lead from soil adhered to the leaves, fruits, or roots of crops, it is important to remove outer leaves of leafy greens, peel vegetables when possible, and thoroughly wash all items with a detergent before consumption.

CONCLUSIONS

A pattern of lead transference from soil through the root to the stem and leaves of garden crops was found. This pattern is a concern particularly for urban garden plants in which the roots, stems, stalks, or leaves are consumed. Fruiting vegetables had lead concentrations less than the limit of detection. Urban gardeners should test the levels of lead in their soils and develop garden plot alternatives to ensure safety while gardening and minimize the lead contamination hazards in the foods they produce. Any produce from urban gardens should be carefully washed with a mild detergent solution before consumption.

This research was conducted in coordination with health experts from the community, and local citizens were involved in discussions on the research and implications for their health protection measures. In certain residential locations, identifying and understanding the potential source of lead contamination provides information for the community such that simple measures can be applied for protecting their health (e.g., creating a raised bed, or relocating garden areas). Similar practical measures can be applied for more complex sites, to frame land use decisions in a way that can account for localized hot spots without precluding all options of interest to projected future users.

ACKNOWLEDGEMENTS

I would like to particularly thank my graduate advisor Dr. Kimberly Gray, Northwestern University, Evanston, IL for all of her knowledge, guidance, and support. I would also like to thank Dr. Helen Binns, Feinberg School of Medicine, Northwestern University and Mary Ann and J. Milburn Smith Child Health Research Program, Children's Memorial Research Center, Chicago, IL for her indispensable help throughout my work on this project. Finally, I would like to acknowledge Mavis Brown, Erie Family Health Center, Chicago, IL, for assistance with community recruitment and follow-up and Jack Morgan, PhD, Illinois Department of Public Health Laboratory for sample processing. This project was funded by a grant from the U.S. Department of Housing and Urban Development, Grant ILLHR0067-99.

REFERENCES

[1] FINSTER ME, GRAY KA, and BINNS HJ. 2004. Lead Levels of Edibles Grown in Contaminated Residential Soils: A Field Survey. Science of the Total Environment 320:245-57.

[2] HANNA AK, and OH P. 2000. Rethinking urban poverty: A look at community gardens. Bulletin of Science Technology and Society 20:207-216.

[3] HARRIS M. 2000. Urban Edens: Community gardens help neighborhoods nourish the body, heal the spirit and enrich the world. Vegetarian Times 271:79-84.

[4] GALLACHER JEJ, ELWOOD PC, PHILLIPS KM, DAVIES BE, GINNEVER RC, TOOTHILL C, and JONES DT. 1984. Vegetable consumption and blood lead concentrations. Journal of Epidemiology Community Health 38:173-176.

[5] United States Environmental Protection Agency (U.S.EPA). 1997. Exposure Factors Handbook. Washington, D.C., EPA 600/P-95/002Fa.

[6] RAHLENBECK SI, BURBERG A, and ZIMMERMANN RD. 1999. Lead and Cadmium in Ethiopian Vegetables. Bulletin of Environmental Contamination and Toxicology 62:30-33.

[7] United States Environmental Protection Agency (U.S.EPA). 1986. Air quality criteria for lead. Research Triangle Park, N.C., EPA 600/8/83/018F.

[8] NEWS: The Neighborhood Early Warning System. 2002. Chicago, IL: The Center for Neighborhood Technology (CNT). Available: http://www.newschicago.org.

[9] SHINN NJ, BING-CANAR J, CAILAS M, PENEFF N, and BINNS HJ. 2000. Determination of spatial continuity of soil lead levels in an urban residential neighborhood. Environmental Research 81:1-7.

[10] United States Environmental Protection Agency (U.S.EPA). 2003b. Test Methods: SW-846 On-line. Available: http://www.epa.gov/epaoswer/hazwaste/test/3_series.htm.

[11] United States Environmental Protection Agency (U.S.EPA). 2003a. Electronic Code of Federal Regulations: e-CFR. Available: http://www.gpoaccess.gov/cfr/index.html.

[12] STERRETT SB, CHANEY RL, HIRSCH CE, and MIELKE HW. 1996. Influence of amendments on yield and heavy metal accumulation of lettuce grown in urban garden soils. Environmental Geochemistry and Health 18:135-142.

[13] ANDREN P, SCHULTZ A, and VAHTER M. 1988. Environmental exposure to lead and arsenic among children living near a glass works. Science of the Total Environment 77:25-34.

[14] BARMAN SC, and LAL MM. 1994. Accumulation of heavy metals (Zn, Cu, Cd, & Pb) in soil and cultivated vegetables and weeds grown in industrially polluted fields. The Journal of Environmental Biology 15(2):107-115.

[15] United States Environmental Protection Agency (U.S.EPA). 2001. Lead; Identification of Dangerous Levels of Lead: Final Rule. Federal Register, 40 CRF Part 745.

[16] LANPHEAR BP, MATTÉ TD, ROGERS J, CLICKNER RP, DIETZ B, BORNSCHEIN RL, SUCCOP P, MAHAFFEY KR, DIXON S, GALKE W, RABINOWITZ M, FARFEL M, ROHDE C, SCHWARTZ J, ASHLEY P, and JACOBS DE. 1998. The contribution of lead-contaminated house dust and residential soil to children's blood lead levels: a pooled analysis of 12 epidemiologic studies. Environmental Research 79:51-68.

[17] CHANEY RL, STERRET SB, and MIELKE HW. 1984. The potential for heavy metal exposure from urban gardens and soils. In: Proceedings of the Symposium on Heavy Metal in Urban Gardens (J.R. Preer ed). University of the District of Columbia Extension Service, Washington, DC, USA. 37-84.

[18] United States Food and Drug Administration (U.S.FDA). 1998. Danger of Lead Still Linger. FDA Consumer Magazine. January-February.

[19] National Research Council (NRC): Committee on Measuring Lead in Critical Populations, Board on Environmental Studies and Toxicology, Commission on Life Sciences. 1993. Measuring Lead Exposure in Infants, Children, and Other Sensitive Populations. Washington, DC: National Academy Press.

[20] ZIEGLER EE, EDWARDS BB, JENSEN RL, MAHAFFEY KR, and FOMAN SJ. 1978. Absorption and retention of lead by infants. Pediatric Research 12:29-34.

[21] GOMAA A, HU H, BELLINGER D, SCHWARTZ J, TSAIH SW, GONZALEZ-COSSIO T, SCHNAAS L, PETERSON K, ARO A, and HERNANDEZ-AVILA M. 2002. Maternal bone lead as an independent risk factor for fetal neurotoxicity: A prospective study. Journal of Pediatrics 110:110-118.

[22] HERNANDEZ-AVILA M, GONZALEZ-COSSIO T, PALAZUELOS E, ROMIEU I, ARO A, FISHBEIN E, PETERSON KE, and HU H. 1996. Dietary and environmental determinants of blood and bone lead levels in lactating postpartum women living in Mexico City. Environmental Health Perspectives 104:1076-1082.

[23] United States Food and Drug Administration (U.S.FDA). 1993. Guidance document for lead in shellfish. Center for Food Safety & Applied Nutrition. Washington, DC.

[24] MUSHAK P. 1993. New directions in the toxicokinetics of human lead exposure. Neurotoxicology 14:29-42.

[25] MELNYK LJ, BERRY MR, SHELDON LS, FREEMAN NCG, PELLIZZARI ED, and KINMAN RN. 2000. Dietary exposure of children in lead-laden environments. Journal of Exposure Analysis and Environmental Epidemiology 10:723-731.

[26] ROGERS J, CLICKNER R, VENDETTI M, and RINEHART R. 1993. Data Analysis of Lead in Soil. U.S. Environmental Protection Agency, Office of Pollution and Prevention and Toxics. Report Number EPA 747-R-93-011.

[27] SHACKLETTE HT, and BOERNGEN JG. 1984. Professional Paper 1270. Element Concentrations in Soils and Other Surficial Materials of the Conterminous United States, 105.

[28] GULSON BL, DAVIS JJ, and BAWDEN-SMITH J. 1995. Paint as a source of recontamination of houses in urban environments and its role in maintaining elevated blood leads in children. Science of the Total Environment 164:221-235.