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Lead levels of edibles grown in contaminated residential soils: a field survey

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Abstract

Plants grown in lead contaminated soils can accumulate lead from the adherence of dust and translocation into the plant tissue. In order to evaluate the potential health hazard due to the consumption of plants grown in residential gardens contaminated by lead, a survey of the lead concentrations in a typical array of edible vegetables, fruits and herbs was conducted. Samples of garden plants harvested from the field were washed with detergent or water alone to remove adhered soil. They were dried, separated into sections including root, shoot and edible fruit, and then analyzed for lead content using inductively coupled plasma-atomic emission spectrometry (ICP-AES). Soil samples, taken in conjunction with the plant harvesting, were analyzed using flame atomic absorbance (FAA). A pattern of lead transference from soil through the root to the stem and leaves of garden crops was found. The majority of the lead was concentrated in the roots (root:soil ranging from 0.02 to 0.51), with some translocation into the shoots (shoot:soil as high as 0.10). This pattern is a concern particularly for crops in which the root, stems, stalks or leaves are edible. The lead concentration in fruiting vegetables was less than the detection limit of 10 ppm (microgram lead/gram dry plant matter). Some edible portions of the leafy vegetables and herbs, however, were found to have lead levels that, if consumed, could contribute to the total body burden of lead. Therefore, urban gardeners should test the lead levels in their soils and develop strategies to ensure safety.

Keywords: Lead; Soil; Chicago; Lead exposure; Edible; Vegetable; Herb; Fruit

1. Introduction

Lead is a widely distributed and ubiquitous element in the environment (CDC, 1991; Nriagu, 1998), which does not biodegrade or decay. It is a highly toxic element to humans and most other forms of life. Children, infants and fetuses are at particularly high risk for lead's neurotoxic and developmental effects. The concentrations of lead in the dust, soil, air and water of children's environments are associated with children's elevated blood lead levels (Angle et al., 1984; Lanphear et al., 1998). Lead ingestion by women of

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childbearing age may impact both the woman's health (Lustberg and Silbergeld, 2002) and that of her fetus, for ingested lead is stored in the bone and released during gestation (Gomaa et al., 2002).

Lead contamination is generally higher in urban areas that display an older housing stock with lead-containing paint, a high concentration of industry (i.e. point source emitters) and heavy traffic (CDC, 1991; USEPA, 1998). These vectors have transmitted lead into an array of lasting hazards, including lead contamination of urban soil (Mielke and Reagan, 1998; Shinn et al., 2000). Since lead is highly immobile in soils (USEPA, 1986), concern about soil contamination by lead persists despite the fact that most lead was removed from residential paints and gasoline approximately 25 years ago. Lead is distributed widely in the urban environment as a result of the weathering, chipping, scraping, sanding and sand blasting of structures bearing lead-based paint (Gulson et al., 1995; Yaffe et al., 1983). Soil lead levels are generally highest at foundations of building that have been painted with exterior lead-containing paint (Demayo et al., 1982; Rogers et al., 1993). In addition, elevated lead levels persist in the soil near heavily traveled roads as a result of vehicle emissions from the combustion of gasoline containing tetraethyl lead (LaBelle et al., 1987; Mielke et al., 1983). In 2001, the US Environmental Protection Agency (USEPA) established a soil lead hazard cut off value of 400 parts per million (ppm) for bare soil in child play areas and an average of 1200 ppm for bare soil in the remainder of the yard (USEPA, 2001).

Urban soils are often highly contaminated (Mielke, 1994). In Baltimore, for instance, lead levels in garden soils were reported as high as 10 900 parts per million (ppm) (Mielke et al., 1983), and in Chicago, residential soil lead contaminations have been found at levels as high as 7950 ppm (Shinn et al., 2000). As a point of reference, naturally occurring background concentrations of lead in surface soils have a mean value of 19 ppm and are generally in the range of 10–70 ppm for the conterminous United States (Shacklette and Boerngen, 1984).

Relationships and modes of transfer of lead from contaminated soil to children have been investigated. Soils contaminated with lead are a health risk, particularly when ingested. During play, lead can contaminate children's hands and may be transmitted to the mouth during oral behaviors (Lanphear et al., 1998). Some children have particular high rates of geophagia (Calabrese et al., 1989; Simon, 1998) and this behavior has been shown to be associated with higher blood lead levels (Lanphear et al., 2002). Track in of soil or exterior dust may contribute to the interior dust lead hazard, which is strongly associated with children's elevated blood lead levels (Lanphear et al., 1998). The ingestation of lead from fruits and vegetables grown in the home environment is another potential route of exposure that has received less attention, but may prove to be a recurring source of lead for both children and adults (Gallacher et al., 1984; USEPA, 1997). 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 (Rahlenbeck et al., 1999; USEPA, 1986). Therefore, through these diverse mechanisms, lead deposited into soil becomes a persistent and long-term source of lead exposure for humans, particularly children.

In recent years, urban gardening has become increasingly popular in nearly all socioeconomic groups in the United States (Hanna and Oh, 2000; Harris, 2000). For some individuals, gardening may be adopted as a way to provide fresh produce and save on food costs; while for others, it is a means of relaxation and enjoyment. Traditionally, the agricultural community has given little attention to the potential health effects of contaminated urban soil (Chaney et al., 1984), even though it seems intuitive that urban gardeners are at potential risk for lead exposure from contaminated soil. Potential mechanisms of lead ingestion include oral contacts with soil-contaminated hands and by direct ingestion of lead-contaminated produce. One study, based in Wales, United Kingdom, found a direct association between ingestion of homegrown produce and blood lead levels in women of childbearing age (Gallacher et al., 1984).

Although it is known that all plants accumulate lead to some extent, little is known about the efficiency of lead accumulation in plants typically

grown in urban residential gardens. Interest in this topic emerged when the development and harvesting of numerous gardens by residents was observed in an area in which an intervention trial related to soil lead contamination was being conducted. When considering the current research on the presence of lead in edible plants (Andren et al., 1988; Dabeka et al., 2002; Larsen et al., 2002; Rahlenbeck et al., 1999; Samsoe-Petersen et al., 2002; Sterrett et al., 1996; Voutsa et al., 1996), 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. 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.

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 and to guide the development of safety recommendations for urban gardening enthusiasts. 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 (2000 and 2001) in one Chicago neighborhood.

2. Methods

The field survey occurred in two areas, approximately 1 mile apart, within the West Town neighborhood of Chicago in the late summer of 2000 and 2001. The north area was 6 blocks and the south area consisted of 4 blocks. The homes and apartments in the north and south areas 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 (NEWS, 2002). All homes were built before 1900 (range 1872–1899). Major roads bordered the study areas to the west and south, and minor roads to the north and west. 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 (Shinn et al., 2000), with median values of 2289 ppm and 1263 ppm.

Table 1
Plant types collected

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				

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. 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 (early September 2000 and September 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 1.

During the first year (2000), 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 accumu-

lated and stored lead and where potential exposure hazards might exist. In the following year (2001), 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 four to six sub samples of the surface soil (corresponding to a depth of 0–3 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 (USEPA, 2003b). 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 (USEPA, 2003a). Seven samples of lead free soil were identically spiked at a concentration of approximately five times the detection limit and analyzed. The standard deviation of the measurements was multiplied by the *T* value for seven replicates (3.143) to obtain the method detection limit. 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.

For the purposes of analysis, the samples were pooled across species and separated into three different groups based upon plant type (i.e. fruiting vegetables, leafy vegetables and herbs, and root vegetables). The data and frequency information

Table 2a
Fruit

Plant type	Preparation technique	Lead concentration[a]			
		Soil (ppm)	Root[b] (μg/g)	Shoot[b] (μg/g)	Edible[b] (μg/g)
Apple	Water	722	–	–	<10
Apple	Water	616	–	–	<10
Cantaloupe	Detergent	27	–	–	<10
Grape	Water	1020	166	<10	<10
Grape	Water	810	140	<10	<10
Grape	Detergent	1600	–	–	<10
Grape	Water	944	481	<10	<10
Strawberry	Water	399	96	20	<10
Strawberry	Water	496	224	11	<10
Strawberry	Detergent	380	–	–	<10
Strawberry	Detergent	560	–	–	<10
Watermelon	Detergent	29	–	–	<10

[a] The dash '–' indicates that a sample of this type was not taken.
[b] Plant sample concentrations are presented in micrograms of lead per gram of dry plant matter.

Table 2b
Fruiting vegetables

Plant type	Preparation technique	Lead concentration[a]			
		Soil (ppm)	Root[b] (μg/g)	Shoot[b] (μg/g)	Edible[b] (μg/g)
Bean	Water	1180	209	<10	<10
Bean	Water	616	49	<10	<10
Bell pepper	Water	589	71	11	<10
Bell pepper	Water	1360	146	16	<10
Bell pepper	Water	1310	218	12	<10
Bell pepper	Detergent	1500	–	–	<10
Bell pepper	Detergent	820	–	–	<10
Bell pepper	Detergent	990	–	–	<10
Bell pepper	Detergent	200	–	–	<10
Corn	Water	1340	118	<10	<10
Corn	Detergent	700	–	–	<10
Cucumber	Water	549	59	32	<10
Cucumber	Water	1070	98	71	<10
Cucumber	Water	792	55	15	<10
Cucumber	**Water**	**1280**	**396**	**125**	**81**
Cucumber	Detergent	540	–	–	<10
Cucumber	Detergent	2100	–	–	<10
Cucumber	Detergent	1400	–	–	<10
Hot pepper	Water	68	10	<10	<10
Hot pepper	Water	152	21	<10	<10
Hot pepper	Water	1700	180	84	<10
Hot pepper	Water	513	49	23	<10
Hot pepper	Detergent	790	–	–	<10
Hot pepper	Detergent	1000	–	–	<10
Hot pepper	Detergent	1100	–	–	<10
Hot pepper	Detergent	110	–	–	<10
Hot pepper	Detergent	130	–	–	<10
Hot pepper	Detergent	340	–	–	<10
Squash, Acorn	Detergent	930	–	–	<10
Squash, Butternut	Detergent	250	–	–	<10
Tomato	Water	3470	715	22	<10
Tomato	Water	1380	111	30	<10
Tomato	Water	334	70	<10	<10
Tomato	Water	169	14	<10	<10
Tomato	Water	432	118	25	<10
Tomato	Detergent	800	–	–	<10
Tomato	Detergent	990	–	–	<10
Tomato	Detergent	460	–	–	<10
Tomato	Detergent	250	–	–	<10
Zucchini	Water	235	52	<10	<10

[a] The dash '–' indicates that a sample of this type was not taken.
[b] Plant sample concentrations are presented in micrograms of lead per gram of dry plant matter.

are presented in Tables 2a, 2b, 3 and 4. Fisher's exact test was used to examine the relationship between lead in leafy edibles (any vs. undetected) and washing technique (water vs. detergent). Analyses of soil and root lead concentration were log base 10 transformed to achieve normal distributions. All analyses involving continuous measures of lead content were conducted using log-transformed data. Pearson or Spearman's correlation, as appropriate, was used to examine the relationships between soil, root and shoot lead concentration. The relationship between soil lead and root

Table 3
Leafy vegetables and herbs

Plant type	Preparation technique	Lead concentration[a]		
		Soil (ppm)	Root[b] (μg/g)	Edible shoot[b] (μg/g)
Basil	Detergent	280	–	<10
Cabbage	Water	612	46	<10
Cabbage	Water	208	10	<10
Cabbage	Water	515	45	<10
Cilantro	**Water**	**2110**	**79**	**49**
Collard greens	**Water**	**4580**	**201**	**12**
Coriander	**Water**	**982**	**141**	**39**
Ipasote	**Detergent**	**550**	–	**14**
Lemon balm	**Water**	**1110**	**420**	**20**
Mint	Water	2120	149	<10
Mint	Detergent	1400	–	<10
Mint	**Water**	**847**	**161**	**11**
Mint	**Water**	**2270**	**592**	**60**
Mint	**Detergent**	**920**	–	**15**
Mint	**Detergent**	**2300**	–	**12**
Mint	Detergent	730	–	<10
Mint	Detergent	370	–	<10
Mint	Detergent	810	–	<10
Mustard greens	Detergent	1100	–	<10
Parsley	Water	88	10	<10
Parsley	Detergent	270	–	<10
Red chard	Detergent	1000	–	<10
Rhubarb, Green	**Water**	**1010**	**68**	**36**
Rhubarb, Green	Detergent	1000	–	<10
Rhubarb, Red	Water	2320	81	<10
Rhubarb, Red	Detergent	1700	–	<10
Sage	Water	627	80	<10
Sage	Detergent	190	–	<10
Swiss chard	**Water**	**902**	**112**	**22**
Swiss chard	**Detergent**	**910**	–	**24**
Thyme	Water	106	15	<10

[a] The dash '–' indicates that a sample of this type was not taken.
[b] Plant sample concentrations are presented in micrograms of lead per gram of dry plant matter.

Table 4
Root vegetables

Plant type	Preparation technique	Lead concentration[a]		
		Soil (ppm)	Edible root[b] (μg/g)	Shoot[b] (μg/g)
Carrot	**Water**	**1890**	**10**	**<10**
Onion	**Water**	**616**	**21**	**<10**
Radish	**Water**	**533**	**12**	**<10**
Radish	**Detergent**	**960**	**18**	–

[a] The dash '–' indicates that a sample of this type was not taken.
[b] Plant sample concentrations are presented in micrograms of lead per gram of dry plant matter.

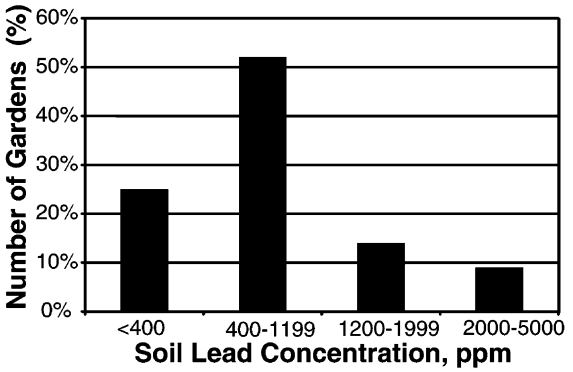

Fig. 1. Distribution of soil lead concentration ($n=87$).

lead concentration was examined using analysis of variance. In analyses for which plant samples tested below the limit of detection, a value of 7 ppm (limit of detection/$\sqrt{2}$) was used in the statistical analyses (Hornung and Reed, 1990).

3. Results

3.1. Samples and soil lead

Garden produce samples ($n=87$) were obtained from the 17 properties, including 11 properties in the north area and 6 in the south area. A range of 1–29 plants was sampled per property (10 properties had one or two plants sampled, five properties had 3–8 and two 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. The distribution of soil lead levels is shown in Fig. 1.

3.2. Plants

The complete set of results for the soil and plant analyses is found in Tables 2, Tables 3 and 4. Tables 2a and 2b include the lead levels associated with all of the fruit and fruiting vegetable plants, Table 3 contains the lead level data for the leafy vegetables and herbs and Table 4 separates out the root vegetable crops. For the purpose of statistical analysis, all of the plant samples were pooled with respect to type and portion, irrespective of morphology. In addition, in each table any sample that was found to have a detectable level of lead in the edible portion is highlighted in bold.

The results in Tables 2a and 2b reveal 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 in Table 3 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, Fisher's exact test $P=0.27$). In addition, Table 4 illustrates that although only four root vegetables were sampled, all of those analyzed exhibited detectable lead concentration in the edible section (or adhered to the edible section, since three of four were water-washed).

3.3. 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, Fig. 2 shows this phenomenon, the proximal to distal transference of lead,

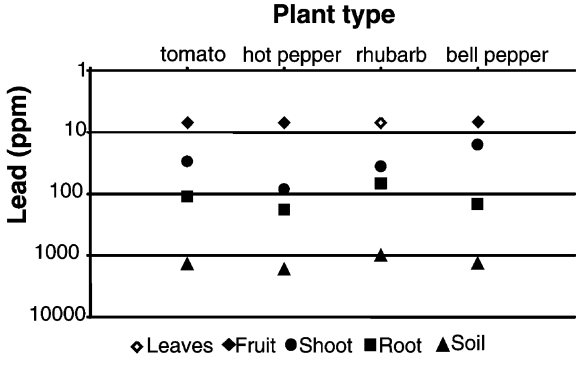

Fig. 2. Movement of lead within the plant.

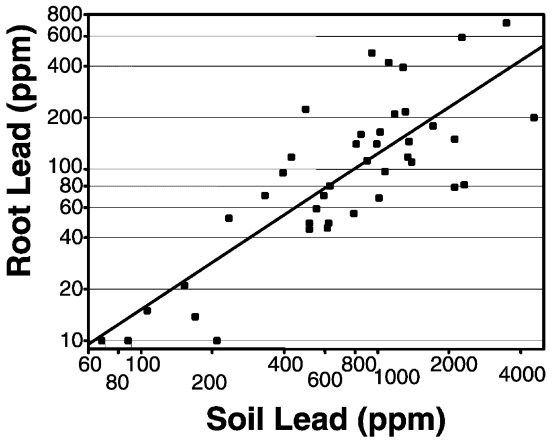

Fig. 3. Relationship of root lead and soil lead.

for a tomato, hot pepper, rhubarb and bell pepper plant, which were collected in 2000, during the first summer of this study. These samples were all subjected to water wash only.

3.4. 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 (Pearson correlation, $r=0.556$, $P<0.001$). 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 Fig. 3 display the root lead concentration vs. the soil lead concentration. In an analysis of variance model, soil lead concentration accounted for a majority of the variation in root lead concentration ($F=75.2$, $P<0.001$, adjusted $r^2=0.65$). Root lead concentration had a median value of 12% of soil lead concentration (range 3–51%).

Fig. 4 shows the relationship of shoot and soil lead concentration, labeled by wash method and plant type, for the 56 fruiting and leafy plants. 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 (S.D. 21%, range 3–72%), while the shoot lead concentration had a median value of 2% of soil lead (range 0.2–10%). Among the shoots tested, there was only one of 13 samples with a soil lead result less than the US regulatory soil lead hazard standard of 400 ppm and detectable shoot lead, while 42% (18/43) of shoot samples grown at a soil lead of 400 ppm or higher had detectable shoot lead (Chi-square, $P=0.001$). 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 level was 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 Fig. 5. No significant relationship was found between lead content of the edible and soil lead concentration (Spearman correlation coefficient, $\rho=0.174$, $n=17$, $P=0.503$).

4. Discussion

This urban-based screening study demonstrated that all garden vegetable plants grown in a contaminated soil accumulate lead to some level. There exists a strong relationship between soil lead and root lead concentration and less predictable rela-

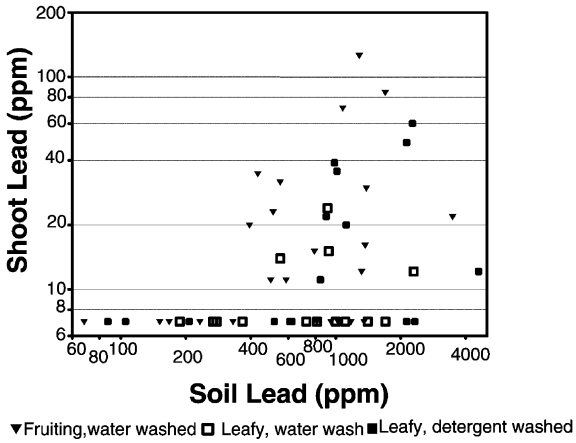

Fig. 4. Relationship of soil lead and lead content of the shoot by washing method.

tionships 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.

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 (Rahlenbeck et al., 1999; Sterrett et al., 1996). 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 (Andren et al., 1988; Barman and Lal, 1994; Rahlenbeck et al., 1999). 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 vs. detergent-washed samples. Thus, the power to detect a difference was limited. Detergent washing of edibles grown in urban soils is, nonetheless, recommended.

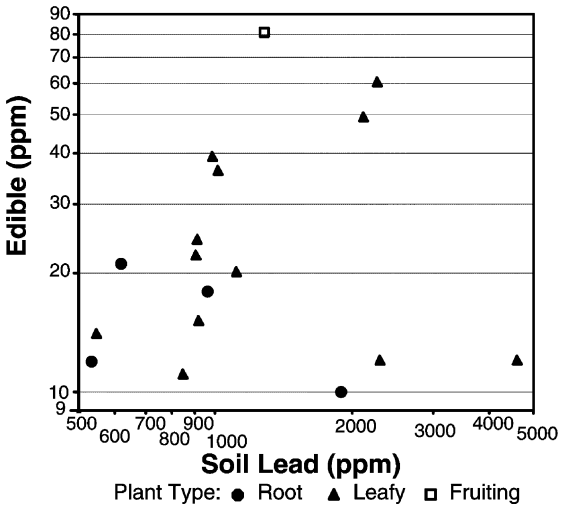

Fig. 5. Edible plant portions and soil lead relationship.

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 (USEPA, 2001). Although some research indicates that soil ingestion, which is primarily due to a child's hand to mouth activity (Lanphear et al., 1998), allows much greater lead exposure than the consumption of garden vegetables grown in the contaminated soil (Chaney et al., 1984), these data suggest that an additional hazard associated with eating plants grown in urban gardens does exist.

4.1. 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 (USFDA, 1998), 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 (NRC, 1993). The residual lead accumulates in mineralizing tissues (i.e. bones and teeth). Children, however, can absorb anywhere from 30 to 75% of ingested lead (USFDA, 1998) and an infant can excrete only approximately 5 $\mu g\ kg^{-1}\ day^{-1}$ (Ziegler et al., 1978). 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) (Gomaa et al., 2002), particularly with low dietary calcium intake (Hernandez-Avila et al., 1996). 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 g), with a lead concentration of 49 μg of lead per gram dry weight of sample, they would be ingesting 85.75 μg of lead. As a result, this value would contribute to their total body burden of lead, for it exceeds the USFDA'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 (USFDA, 1993). 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 (Mushak, 1993).

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 (Melnyk et al., 2000). 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 (Melnyk et al., 2000). Thus, utilizing the same predictive approach, the estimated ingestion value of 85.75 μg, if added to these average total and mean dietary intake levels and used in the same correlation equations to estimate corresponding BBLs, would result in levels of 9.9 μg/dl and 10.2 μg/dl, respectively. 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).

4.2. 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 5 lists recommendations urban gardeners may elect to follow so to lower risks associated with gardening. 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 (Rogers et al., 1993). 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

Table 5
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.

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 US regulatory soil hazard standard that is considered safe for child play (USEPA, 2001). 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 (Shacklette and Boerngen, 1984).

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 (Gulson et al., 1995; Shinn et al., 2000). 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 (Sterrett et al., 1996). 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.

5. 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.

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References

Andren P, Schultz A, Vahter M. Environmental exposure to lead and arsenic among children living near a glass works. Sci Total Environ 1988;77:25–34.

Angle CR, Marcus A, Cheng IH, McIntire MS. Omaha childhood blood lead and environmental lead—a linear total exposure model. Environ Res 1984;35(1):160–170.

Barman SC, Lal MM. Accumulation of heavy metals (Zn, Cu, Cd and Pb) in soil and cultivated vegetables and weeds grown in industrially polluted fields. J Environ Biol 1994;15(2):107–115.

Calabrese EJ, Barnes R, Stanek EJ III, Pastides H, Gilbert CE, Veneman P, Wang X, Lasztity A, Kostecki PT. How much soil do young children ingest: an epidemiologic study. Regul Toxicol Pharmacol 1989;10:123–137.

CDC (Centers for Disease Control). Preventing lead poisoning in young children: a statement by the centers for disease control. Atlanta, GA: US Dept. of Health and Human Services, 1991.

Chaney RL, Sterret SB, Mielke HW. The potential for heavy metal exposure from urban gardens and soils. In: Preer JR, editor. Proceedings of the Symposium on Heavy Metal in Urban Gardens, University of the District of Columbia Extension Service, Washington, DC, USA, 1984:37–84.

Dabeka RW, McKenzie AD, Pepper K. Lead contamination of raisins sold in Canada. Food Addit Contam 2002;19(1):47–54.

Demayo A, Taylor MC, Taylor KW, Hodson V. Toxic effects of lead and lead compounds on human health, aquatic life, wildlife plants and livestock. Crit Rev Environ Control 1982;12:257–305.

Gallacher JEJ, Elwood PC, Phillips KM, Davies BE, Ginnever RC, Toothill C, Jones DT. Vegetable consumption and blood lead concentrations. J Epidemiol Community Health 1984;38:173–176.

Gomaa A, Hu H, Bellinger D, Schwartz J, Tsaih SW, Gonzalez-Cossio T, Schnaas L, Peterson K, Aro A, Hernandez-Avila M. Maternal bone lead as an independent risk factor for fetal neurotoxicity: a prospective study. J Pediatr 2002;110:110–118.

Gulson BL, Davis JJ, Bawden-Smith J. Paint as a source of recontamination of houses in urban environments and its role in maintaining elevated blood leads in children. Sci Total Environ 1995;164:221–235.

Hanna AK, Oh P. Rethinking urban poverty: a look at community gardens. Bull Sci Technol Soc 2000;20:207–216.

Harris M. Urban Edens: community gardens help neighborhoods nourish the body, heal the spirit and enrich the world. Vegetarian Times 2000;271:79–84.

Hernandez-Avila M, Gonzalez-Cossio T, Palazuelos E, Romieu I, Aro A, Fishbein E, Peterson KE, Hu H. Dietary and environmental determinants of blood and bone lead levels in lactating postpartum women living in Mexico City. Environ Health Perspect 1996;104:1076–1082.

Hornung RW, Reed LD. Estimation of average concentration in the presence of non-detectable values. Appl Occup Environ Hyg 1990;5:46–51.

LaBelle SJ, Lindahl PC, Hinchman RR, Ruskamp J, McHugh K. Pilot study of the relationship of regional road traffic to surface–soil lead levels in Illinois. Argonne National Laboratory, Energy and Environmental Systems Division, Center for Transportation Research, Publication ANL/ES-154, 1987.

Lanphear BP, Matté TD, Rogers J, Clickner RP, Dietz B, Bornschein RL, Sucop P, Mahaffey KR, Dixon S, Galke W, Rabinowitz M, Farfel M, Rohde C, Schwartz J, Ashley P, Jacobs DE. The contribution of lead-contaminated house dust and residential soil to children's blood lead levels: a pooled analysis of 12 epidemiologic studies. Environ Res 1998;79:51–68.

Lanphear BP, Hornung R, Ho M, Howard CR, Eberle S, Knauf K. Environmental lead exposure during early childhood. J Pediatr 2002;140:40–47.

Larsen EH, Andersen NL, Moller A, Petersen A, Mortensen GK, Petersen J. Monitoring the content and intake of trace elements from food in Denmark. Food Addit Contam 2002;19(1):33–46.

Lustberg M, Silbergeld E. Blood lead levels and mortality. Arch Intern Med 2002;162:2443–2449.

Melnyk LJ, Berry MR, Sheldon LS, Freeman NCG, Pellizzari ED, Kinman RN. Dietary exposure of children in lead-laden environments. J Expos Anal Environ Epidemiol 2000;10:723–731.

Mielke HW. Lead in New-Orleans soils: new images of an urban environment. Environ Geochem Health 1994;16:123–128.

Mielke HW, Anderson JC, Berry KJ, Mielke PW, Chaney RL, Leech M. Lead concentrations in inner-city soils as a factor in the child lead problem. Am J Public Health 1983;73(12):1366–1369.

Mielke HW, Reagan PL. Soil is an important pathway of human lead exposure. Environ Health Perspect 1998;106(Suppl. 1):217–229.

Mushak P. New directions in the toxicokinetics of human lead exposure. Neurotoxicol 1993;14:29–42.

NRC (National Research Council): Committee on Measuring Lead in Critical Populations, Board on Environmental Studies and Toxicology, Commission on Life Sciences. Measuring lead exposure in infants, children and other sensitive populations. Washington, DC: National Academy Press, 1993.

Nriagu JO. Paleoenvironmental research-tales told in lead. Science 1998;281:1622–1623.

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

Rahlenbeck SI, Burberg A, Zimmermann RD. Lead and cadmium in Ethiopian vegetables. Bull Environ Contam Toxicol 1999;62:30–33.

Rogers J, Clickner R, Vendetti M, Rinehart R. Data Analysis of Lead in Soil. US Environmental Protection Agency, Office of Pollution and Prevention and Toxics. Report Number EPA 747-R-93-011, 1993.

Samsoe-Petersen L, Larsen EH, Larsen PB, Bruun P. Uptake of trace elements and PAHs by fruit and vegetables from contaminated soils. Environ Sci Technol 2002;36:3057–3063.

Shacklette HT, Boerngen JG. Professional Paper 1270. Element Concentrations in Soils and Other Surficial Materials of the Conterminous United States, 1984, p. 105.

Shinn NJ, Bing-Canar J, Cailas M, Peneff N, Binns HJ. Determination of spatial continuity of soil lead levels in an urban residential neighborhood. Environ Res 2000;81:1–7.

Sterrett SB, Chaney RL, Hirsch CE, Mielke HW. Influence of amendments on yield and heavy metal accumulation of lettuce grown in urban garden soils. Environ Geochem Health 1996;18:135–142.

Simon SL. Soil ingestion by humans: a review of history, data and etiology with application to risk assessment of radioactively contaminated soil. Health Phys 1998;74:647–672.

USEPA (United States Environmental Protection Agency). Air quality criteria for lead. NC: Research Triangle Park, 1986. (EPA 600/8/83/018F).

USEPA (United States Environmental Protection Agency). A summary of studies addressing the source of soil–lead. In: Study abstracts. vol. II, 1998, EPA 747-R-98-001B.

USEPA (United States Environmental Protection Agency). Exposure Factors Handbook. Washington, DC, 1997, EPA 600/P-95/002Fa.

USEPA (United States Environmental Protection Agency). Lead; Identification of Dangerous Levels of Lead: Final Rule. Federal Register, 2001, 40 CRF Part 745.

USEPA (United States Environmental Protection Agency). 2003a. Electronic Code of Federal Regulations: e-CFR. Available: http://www.access.gpo.gov/nara/cfr/cfrhtml_00/Title_40/40cfr136_00.html [accessed July 2003].

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

USFDA (United States Food and Drug Administration). Guidance document for lead in shellfish. Washington, DC: Center for Food Safety and Applied Nutrition, 1993.

USFDA (United States Food and Drug Administration). Danger of Lead Still Linger. FDA Consumer Magazine. January–February, 1998.

Voutsa D, Grimanis A, Samara C. Trace elements in vegetables grown in an industrial area in relation to soil and air particulate matter. Environ Pollut 1996;94(3):325–335.

Yaffe Y, Flessel CP, Wesolowski JJ, del Rosario A, Guiruis G, Matias V, DeGarmo TE, Coleman GC, Gramlich JW, Kelly WR. Identification of lead sources in California children using the stable isotope ratio technique. Arch Environ Health 1983;38:237–245.

Ziegler EE, Edwards BB, Jensen RL, Mahaffey KR, Foman SJ. Absorption and retention of lead by infants. Pediatr Res 1978;12:29–34.