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INTRODUCTION

Community gardens are community-managed spaces that are open to the public. They differ from other open spaces, such as parks, in that the area is generally reserved for the growing of fruits, vegetables, herbs, and flowers by members of the immediate community. There are hundreds of community gardens located in urban, suburban and rural communities throughout the State of Connecticut. Close by, in New York City, there are over 1900 community gardens, and, in fact, there are community gardens located in every major city in the US, Europe and Australia. Over 6000 community gardens were identified in a recent survey of 38 US cities (AMGA, 1998).

Urban activities such as transportation, construction and manufacturing have resulted in increased heavy metals, notably lead, in the soils surrounding these activities. The most common sources of lead were tetraethyl lead additives in gasoline, and lead-based paint (Ruby et al. 1999). Although much is known with regard to lead exposure in and around houses and soils directly adjacent to houses, little is known about potential lead exposure in community garden soils. Limited studies have confirmed that community garden soils in urban areas can be severely contaminated with lead (US EPA 1998, Finster et al. 2004). In addition to lead, there have been reports of elevated amounts of other heavy metals, such as cadmium, chromium, copper, and zinc, in urban land used for community gardens (Hough et al. 2004, Murray et al. 2004). However, no specific guidelines for the limits of lead and other heavy metals in community garden soils for safe gardening exist.

To assess the extent of soil contamination in Community Garden soils we acquired 174 soil samples from 25 community gardens located in 10 Connecticut cities and towns over the time period from 2004 to 2007 and analyzed them for arsenic (As), cadmium (Cd), copper (Cu), chromium (Cr), nickel (Ni), lead (Pb) and zinc (Zn).

Review of Lead Content in Urban Soils

Historically, lead was used as an ingredient in many industrial products, such as paints, gasoline, batteries and solder. This resulted in widespread lead migration into the soil environment. Consequently, contact with these contaminated soils can cause lead toxicity. Depending on the extent of exposure, lead causes subtle neurological impairment to severe brain, liver and kidney damage. (Mielke et al., 1997; Hettiarachchi and Pierzynski 2004).

Due to these health effects, lead use has been phased out of many manufactured products beginning in the later part of the twentieth century. However, since lead does not degrade, widespread environmental contamination persists to this day. The US EPA has estimated that 18 million home sites in the US have soil lead levels exceeding the 400 mg/kg guideline (US EPA 1996). Lead is commonly associated with industrial sites and has been identified as a major contaminant in about half of the Superfund sites (Hettiarachchi and Pierzynski, 2004).

In populated areas, lead contamination in soils around homes is positively correlated with proximity to urban centers and age of housing. Murray et al. (2004) measured the lead content in hundreds of soil samples taken in an urban watershed in SE Michigan (Rouge River area, including Detroit). They reported that the lead content averaged 15-16 times the background level in industrial and residential areas. Moreover, in specific industrial sites and adjacent neighborhoods, soil lead contents at levels hundreds of times above background were found. In outlying areas, the average soil lead was 8 mg/kg, increasing to an average of 162 in the center of the urban region. Among all samples there was no difference in average lead (mg/kg) between industrial (150 ± 380, n=535), commercial (93 ± 300, n=418) and residential (160 ± 250, n=535) surface soil samples, though the maximum amounts were somewhat less in the residential areas. The average lead in all areas decreased substantially with depth greater than 0.5 m, averaging <40 mg/kg, in all three land use areas sited above. These findings were consistent with another study in Baltimore, MD where the highest elevated soil levels were found toward the city center (US EPA 1998). A relationship between housing age and lead content was reported in a study of soil lead contamination in New Haven, CT (US EPA 1998). Soil samples were taken next to and away from houses constructed between 1910 and 1977. The lead averaged less than the 400 mg/kg EPA guidance level in soils next to houses built after 1960, while it exceeded this level around houses built earlier. In soil next to houses built prior to 1939, the soil lead averaged more than 1200 mg/kg.

There have been a limited number of studies that focused specifically on lead in garden soils. In a study in Baltimore, MD (US EPA 1998), soil samples collected from 422 vegetable gardens located within a 30 mile radius from downtown Baltimore were analyzed for lead. The soil lead ranged from 1 to 10900 mg/kg, and the median soil level was 100 mg/kg. About 20% of the samples exceeded the 400 mg/kg guidance values. The elevated garden soil lead levels were clustered towards the city center. Boon and Soltanpour (1992) analyzed lead extract solutions obtained from 65 garden soil samples in Aspen, Colorado, many of which were contaminated by silver mine dump material. The extractable lead ranged from 10-808 mg/kg versus a background of 10 mg/kg lead. They used a mild chelation extraction method, so direct comparison to the 400 mg/kg soil lead guidance level was not possible. However, mine dump contaminated soils located nearby and analyzed by the standard acid digestion method contained an average of 6375 mg/kg lead. They concluded that the garden soils in these areas could be hazardous. Finster et al. (2004) analyzed 87 soil samples in 17 gardens in the Chicago, Illinois area for lead. They reported that the soil lead ranged from 27 to 4580 mg/kg and averaged 800 mg/kg. The maximum difference between samples within a garden was 3690 mg/kg. About 25% of the samples were below the 400 mg/kg guidance level, while about one half were in the 400-1200 mg/kg range

These examples illustrate the widespread contamination of lead in urban soils. Consequently, many government agencies have published advice on ways to lower lead exposure by remediation of contaminated soils in residential yards and gardens (US EPA 2001, Logan 1993, Rosen 2002, Stehouwer 1999, Finster et. al. 2004). The level of remediation that is recommended is based on the degree of contamination and varies somewhat by State (Table 1). In cases of low to medium soil lead contamination, specific recommendations include: enforcement of a clean hands policy, washing fruits and vegetables, raising soil pH by application of limestone, adding phosphate to tie up the lead, and covering the ground around the plants with mulch to reduce soil splash up onto crops. In cases approaching the upper limits of soil Pb contamination, recommendations include; construction of raised beds using imported clean soil and covering the soil between the beds with such material as mulch, gravel, or pavers. In marginal areas, fruit crops should be grown instead of root crops, herbs or leafy green vegetables. The upper limit in soil lead where gardening is not advisable varies greatly, from a low of 300-400 mg/kg (Rosen 2002, Finster et al. 2004) to 1000-2000 mg/kg (EPA 2001, Logan 1993, Stehouwer 1999).

Table 1. Variation in soil lead concentrations (mg/kg) used by different agencies to estimate level of lead contamination.

Estimate	CT	MN	OH	PA	MA (EPA)
Very High			>3000	>2000	>5000
High	1000	300	1000-3000	1000-2000	2000-5000
Medium	500		500-1000	400-1000	400-2000
Low	<400	<100	<500	150-400	<400
Background	20			<150	

CT- (State of CT 1996), MN-(Rosen 2002), OH-(Logan 1993), PA-(Stehouer 1999), MA –(US EPA 2001).

MATERIAL AND METHODS

Over the time period of 2004-2007, 174 composite soil samples from 25 gardens located in 10 Connecticut cities or towns (Bridgeport (n=2), Hartford (n=2), Middletown (n=1), New Haven (n=11), New London (n=4), Southbury (n=1), Waterbury (n=1), Westport (n=1), Wilton (n=1), and Windsor (n=1)) were collected. The recommended soil sampling procedure is given in Appendix A. The number of composite samples per garden varied from 3 to 18, and averaged 7 per garden. For the purposes of this survey, garden soil is soil that was either imported or native and was situated where a garden was in use or was planned to be in use.

Each composite sample in the plastic bag was sub-sampled by taking out about twenty 5g portions at random which were placed into a 120 ml polypropylene specimen container. The sub-samples were dried at 100^{o}C, passed through a 2mm sieve, weighed (0.5 g in duplicate) into polypropylene vessels, and digested in 5 ml of concentrated nitric acid for 45 minutes at 115^{o}C in a hot block (DigiPrep, SCP Science). After bringing the samples up to a final volume of 50 ml using distilled deionzed water, the total amounts of inorganic analytes were determined by inductively coupled plasma atom emission spectroscopy ICP-AES using a Thermo Atomscan 16, following EPA method 3050 (Stilwell 1993). The inorganic analytes in the soil samples reported here are arsenic (As), cadmium (Cd), chromium (Cr), copper (Cu), nickel (Ni), lead (Pb), and zinc (Zn), in units of mg/kg (or parts per million, ppm).

In three gardens additional samples were taken to determine the effectiveness of soil remediation using raised beds. In this remediation method, imported soil is used to fill raised beds where the produce is grown. Ground cover (typically mulch) is used around the beds to minimize exposure to the native soil. Thus, in this sense, a remediated garden typically contains both native soil and imported soil. This raised bed technique is the least costly. More costly methods involve soil removal of up 2 meters of native soil, followed by replacement with clean fill.

RESULTS

Heavy Metals in Soils

Shown in Table 2 is the range, the number of gardens whose average was below the detection limit (DL) for a given element, the overall average and the overall median heavy metal content from the averaged heavy metal content in each of the 25 community garden soils. For comparison the average amount in a local farm soil (Lockwood Farm, Hamden CT) and the CT State residential limit (Connecticut Standards for Soil Remediation 22a-133k-2) for soils is given. Since the number of soil samples from each garden varied from 3-15, this average does not overweigh the results from any particular garden. For computational purposes values below the DL were assigned a number equal to ½ of the DL. Note that there are wide variations in all of the metals, except Cd where the soil content in the gardens averaged between <0.5-2 mg/kg. Also note that although the average Cu and Zn level in community gardens were elevated with respect to the farm soil, they did not come close to exceeding State limits. The average As level in 3 gardens exceeded the State limits, and the limit was exceeded for Pb in 6 gardens. There was no overlap for As and Pb both exceeding the State limits, so the total percent of gardens where the average content in As or Pb was exceeded was 36%. Conversely, in 25% of the gardens the average soil As was below the DL, while it was below the limit 8% for lead. This wide variability points to the need to sample each garden before growing food crops.

Table 2. Soil range, average, and median heavy metal content (mg/kg) in 25 community gardens.

	Range	# Gardens Avg. <DL	Average	Median	Farm Soil	CT Res. Limit	# Gardens Avg>Limit	% Gardens Avg>Limit
As	<3-58	5	7.3	4.1	<3	10	3	12
Cd	<0.5-2	15	<0.5	<0.5	<0.5	34	0	0
Cr	<8-38	2	15	13	16	3900	0	0
Cu	12-335	0	53	42	16	2500	0	0
Ni	<8-20	2	12	11	13	1400	0	0
Pb	<10-2020	2	324	155	16	400	6	24
Zn	26-310	0	159	154	43	20000	0	0

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Table 3. Heavy metal content in all community garden soil samples (n=174).

	Range	# Samples <DL	Average	Median	Farm Soil	CT Res. Limit	# Samples >Limit	% Samples >Limit
As	<3-92	48	6.0	4.2	<3	10	20	12
Cd	<0.5-3.5	96	0.5	<0.5	<0.5	34	0	0
Cr	<8-42	2	15	14	16	3900	0	0
Cu	<8-900	1	51	40	16	2500	0	0
Ni	<8-27	19	12	12	13	1400	0	0
Pb	<10-3490	10	330	176	16	400	54	31
Zn	14-520	0	176	163	43	20000	0	0

Shown in Table 3 is the range, average, and median heavy metal contents in all of the community garden soil samples taken from 2004-2007, as well as the number of samples below the detection limit. Similar computational practices and comparisons as described for the data in Table 2 were employed for the data in Table 3. Note that in 12% of the samples the As exceeded the limit, and in 31% of the samples the lead content exceeded the State limit. Furthermore, the median level for Pb was far greater than the farm soil, confirming widespread contamination by that element. For As, however, the median level was similar to that in the farm soil and fully 28% of the soil samples were below the DL for As. The extreme variability of the heavy metal contents in both the soil samples and the garden averages point to the need to accurately assess the soil heavy metal profile in each area in every garden.

Shown in Table 4 is the frequency for As and Pb in garden soil averages and in soil samples within given concentration ranges. Approximately 60% of the garden averages and the soil samples were at or below the normal values for As in CT soil (<5 mg/kg). Only 3-4% of the garden averages and samples exceeded the 10 mg/kg by more than a factor of two (>20). Thus, As contamination is more frequently noted (8-9%) just above the limit (10-20 mg/kg As), while significant As contamination (3-4%) is rare. With Pb about one half of the garden averages and samples were below 200 mg/kg, which is equal to one half of the limit (400 mg/kg). About one quarter of the garden averages, and 14% of the samples fell between 200 and 400 mg/kg Pb, levels approaching the limit. Twelve % of the gardens and 23% of the samples were between one and two times the limit (400-800 mg/kg Pb). Twelve % of the garden averages and 8% of the samples exceeded the limit by a factor of two, or more. In total 24% of the garden averages and 31% of the samples exceeded the Pb limit, and 12% exceeded the As limit. Even though Pb contamination occurs more frequently, As contaminated soil occurs in non trivial frequencies and should be included in soil assays.

Table 4- Tabulated frequency (%) of the average soil content in gardens and total soil samples within a given range (mg/kg) for As and Pb.

Range mg/kg	**% Within the Range** Gardens (n=25)	Samples (n=174)
Arsenic		
<3	24	28
3-<5	36	30
5-<10	28	31
10-<20	8	9
>20	4	3
Lead		
<200	52	55
200-400	24	14
401-600	8	18
601-800	4	5
801-1000	8	1
>1000	4	7

The variability of Pb and As within a garden (not shown) ranged from minor to considerable and can be separated into three classes. One class is when all soil samples are below the CT State limits for Pb and As. This situation occurred in 11 (44%) of the gardens tested. In those cases either the remediation carried out was shown to be sufficient or the soil was not contaminated to excess begin with. The second case was high variability within a garden, where localized contamination was detected, and one or more samples exceeded the guidance limit in As or Pb. This occurred in 6 (24%) of the gardens tested. For example, in one garden the lead ranged from 57 to 794 mg/kg Pb (n=6), averaged 296±300, and two samples exceeded the 400 mg/kg limit. In another garden, the lead averaged 237±310 mg/kg over 13 samples, but only 1 (1247 mg/kg Pb) exceeded the limit. In these gardens we suggest that remediation efforts should focus on those grids within the garden where the Pb or As was excessive, or alternatively, that those areas be placed out of the garden growing space. The final case is widespread contamination where the majority of samples exceeded the limit for Pb or As. This occurred in 8 (32%) of the gardens. In these gardens a remediation plan would be suggested for the entire garden, followed by a resampling to ensure that the contaminate concentrations were brought down to levels well below the limits.

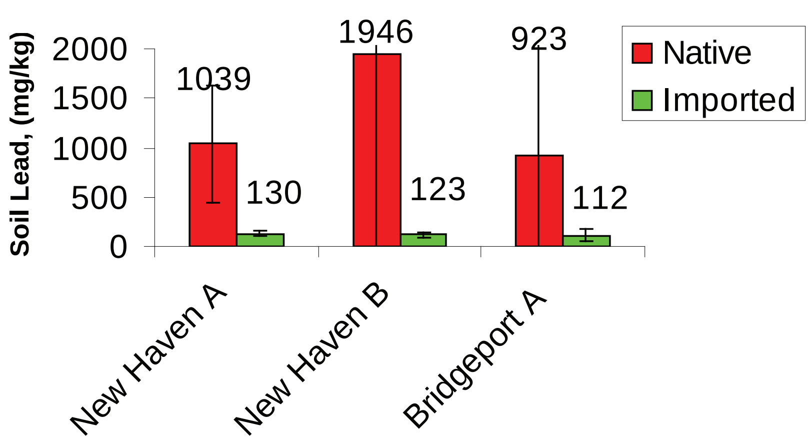

Figure 1. Average lead (mg/kg) in native (N) soils and in imported (I) soils in raised beds from three community gardens. The number of soil samples were, New Haven A, (N,11; I,6), New Haven B (N,5; I,6), Bridgeport A (N,6; I,15).

Site Remediation using Raised Beds

In cases where there is widespread Pb contamination in community garden plots, a common practice is to construct raised beds and to fill them with clean soil imported from another site. In three gardens using raised beds, imported and native soil samples were collected and analyzed for Pb. The results shown in Figure 1 demonstrate the significant reduction in soil Pb in the area where the community gardener is exposed to the soil, and where the edible plants are grown. In total, six of the community gardens sampled in this survey used imported soils (4 raised beds, 2 as fill). In all of these cases the average As and Pb soil levels in the imported soils did not exceed guidelines. Care should be taken to avoid mixing the native soil beneath the raised bed with the clean imported soil. We suggest using porous barriers between these two soil interfaces to minimize mixing and maximize drainage.

CONCLUSIONS

Surveys of the heavy metal levels of soils at 25 community gardens in 10 Connecticut cities show that a considerable number are contaminated with lead and arsenic. The survey results indicate that 36 percent of the gardens had at least one soil sample greater than the Connecticut Department of Environmental Protection's limit for lead and 20 percent of the gardens had at least one sample greater than the limit for arsenic. Often, levels varied considerably within a single garden.

The Cu and Zn in the garden soils were all elevated with respect to the background levels represented by the farm soil, but in no cases did they exceed the State limits. The Cd, Ni and Cr levels were at or near background in all samples. Similar results were reported by Murray et al. (2004), except that all of metals increased with proximity to the urban center.

Remediation using soil imported from uncontaminated sites and used to fill raised beds was shown to be an effective, cost efficient way to reduce potential exposure of heavy metals to community gardeners. In addition, physical barriers should surround the raised beds to eliminate direct exposure to the contaminated soil. Such barriers include 10-15 cm of mulch applied on top of heavy duty porous landscape fabric.

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APPENDIX A

Soil sampling protocol for heavy metals in soils

Site assessment

1. Tour the site with someone who is familiar with its historic and current use.

2. Determine if any undisturbed native soils (former front/back yard) are on the site. These areas should be sampled separately from others.

3. If an original structure is on the site, the soil immediately adjacent should be sampled separately.

4. Determine if there is any imported soil that may have been introduced on the site after demolition. These soils should be sampled separately.

5. Make notes of the horticultural suitability (planting depth, estimated sunlight exposure, gardening logistics, etc.) of each area sampled.

Sampling procedure

1. Map garden and divide sampling areas into grids (normally 10-15 sample areas)

2. Use a stainless steel sampling probe or a stainless steel garden hand spade.

3. Sample to ordinary tillable depth or, if shallow, to the depth possible on site.

4. Each sample should be representative of the area. Remove 8-12 cores from random spots within the area.

5. Deposit cores directly into new, thick walled high quality plastic bags (such as a 1 gallon zipper freezer bag, by Ziploc or Hefty). If using the hand spade, deposit sub-samples (about 100-150 ml each) into a 2-3 liter plastic bucket, mix, and place about 1-1.5 liters of the soil mix into the plastic bag.

6. Label each bag clearly with a name or number that the site contact will recognize.

Grid Areas- Normally, a sample grid is around 3x3 meters (10x10 feet) or if the area is very large then it can be 7x7 meters (20x20 feet) or more. The grids do not have to be square or equally sized. A separate grid near fences or house perimeters, for example, may be 1-2 meters wide by 5-10 meters long.

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