Gardening on Brownfields Sites: Evaluating trace element transfer from soil to plants and their transformations in soils

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Abstract
Tens of thousands of brownfields (abandoned or underutilized properties where known or potential environmental issues are an obstacle to redevelopment) can be found in cities, towns, and rural areas across the USA. Our work has focused, in part, on the conversion of brownfields to garden areas and is motivated by the increasing interest in locally produced foods. Challenges of converting brownfields to community gardening sites will be discussed using one newly established urban community garden site located in Kansas City as an example. This site had mildly elevated levels of lead (Pb) and some detectable levels of dichlorodiphenyltrichloroethane/ dichlorodiphenyldichloroethylene (DDT/DDE). Suitable safety/corrective measures were suggested and implemented after thorough evaluation of soil properties. Measures focused on reducing both direct (soil-human) and indirect (soil-plant-human) exposure of Pb and/or DDT/DDE to the gardeners and their children. In addition, field test plots were established within the community garden and three crop types with three very different growth and contaminant uptake patterns were planted. Effectiveness of selected site-specific soil amendments to reduce bioavailability of Pb will be evaluated. Different methodologies will be utilized throughout the project to understand the significance of potential soil-plant-human exposure pathway of contaminants while gardening on mildly contaminated sites. Efforts will be made to understand relationships between key soil properties and contaminant bioavailability.

Key Words
Brownfields, trace elements, bioavailability

Introduction
Vacant or abandoned properties with real or perceived contamination issues are called "brownfields". In the U.S., approximately 450,000 brownfields sites cover an estimated 5 million acres (2 million hectares). Since 1995, the Environmental Protection Agency (EPA) provides funds for assessment and cleanup to bring these sites back to beneficial use. Our work focuses on the potential conversion of brownfields to garden areas and is motivated by the increasing interest in locally produced foods. In the U.S.,there was a 6.8% increase in farmers markets between 2006 and 2008, with 4,600 such markets in 2008, and approximately 18,000 community gardens present in the U.S. and Canada Gardening on brownfields presents challenges beyond more typical brownfields redevelopment projects because of increased chances of human exposure to contaminants through direct soil ingestion and indirect food-chain transfer. Lead from the use of leaded paint and gasoline, arsenic (As) from arsenate pesticides along with dichlorodiphenyltrichloroethane (DDT) and chlordane can be most common and significant contaminants. It is apparent that most of the community gardening groups interested in gardening on brownfields are disproportionately located in urban areas. Many of the brownfields that are candidates for urban gardening were formerly residential areas.
It is well known that the total concentration of trace elemental and other contaminants in the soil environment and/or plants does not strongly correlate to bioavailability or potential toxicity. Therefore, a careful assessment of site specific contaminants and soil characteristics is essential for designing suitable safety measures required for minimizing the direct or indirect transfer of contaminants to the gardeners.
Our objective is to work with select community-based gardening initiatives to evaluate uptake of trace elements and other contaminants by food crops and to develop recommendations for seedbed preparation and corrective/protective actions to address potential contaminant transfer to food crops and consumers.

Materials and Methods
Evaluation of sites throughout the U.S. to be included in this project is on-going. Several suitable sites have been identified thus far and one of them will be discussed below as an example.
The Washington Wheatley (WW) site in Kansas City, Missouri is located in a residential neighborhood. The site is approximately 42m x 37m and was formerly occupied by four residences. The site was screened for trace metals using a hand-held x-ray fluorescence spectrometer (XRF). Screening locations were established

by using a 10 feet grid system, including 39 screening locations, to facilitate generating spatial distribution maps of trace elements of interest. GPS was used to log the exact screening pointsBased on the screening results, soil samples were collected at four locations showing the highest trace element readings. The soil samples were collected from two depths (0-15 cm and 15 to 30cm) for analysis of selected soil chemical properties (available N, pH, electrical conductivity (EC), organic C (OC) and available phosphorus (P) using appropriate procedures (Sparks 2005)) and confirmation analyses of total trace elemental concentration in soils. Additionally, three soil samples (C1 through C3, Figure 1) were initially collected for chlordane analyses and six (C4 through C9, Figure 1) additional soil samples were collected later for DDT and dichlorodiphenyldichloroethylene (DDE) analyses.

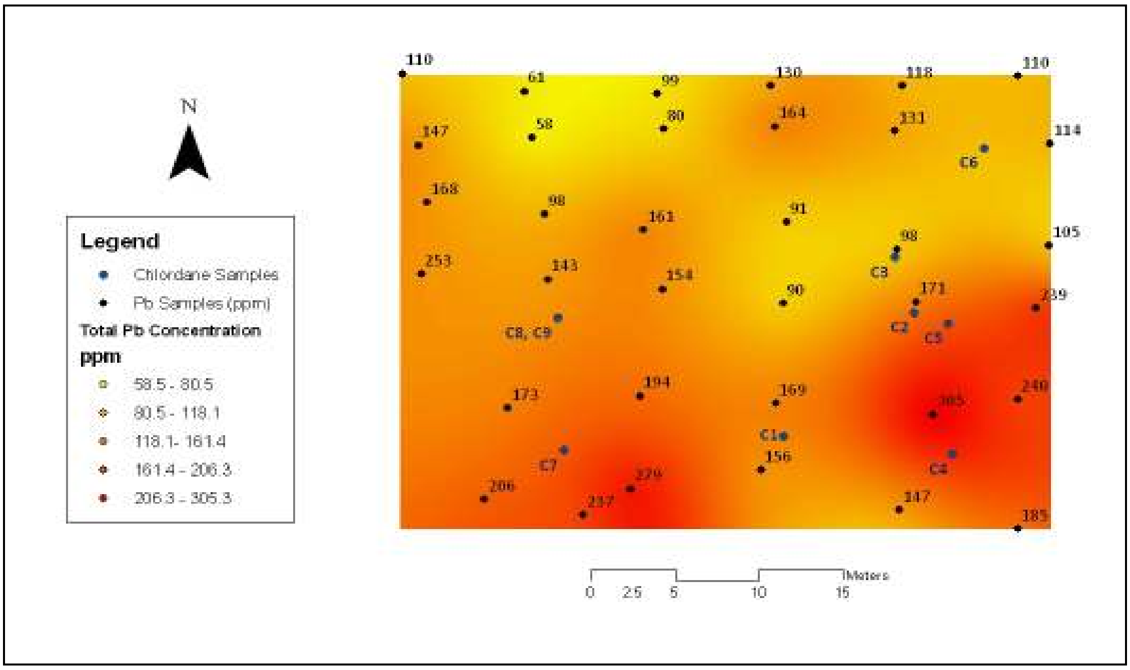

Figure 1. Total Pb concentration map of the Washington Wheatley site generated using the Pb concentrations measured by the portable x-ray fluorescence analyzer. Soil sampling locations for DDT and DDE (C1 through C9) are also shown.

Test plots were established in early June for the summer 2009 gardening season and initial soil samples from each subplot (18) were collected. The basic experimental design was a split plot design with three replications. The main plot factor was compost treatment (2, no compost or compost added) and was arranged in a randomized complete block. The subplot factor was plant type. The three vegetables planted were Swiss chard (cultivar Gator Perpetual Spinach, seed was obtained from Fedco, Waterville, ME), sweet potato (cultivar Beauregard sweet potato from Kansas State Research and Extension Center, Haysville, KS) and tomato (cultivar Biltmore from Seminis, Oxnard, CA). At the end of the growing season, plants were harvested from test plots as well as from some randomly selected community gardening plots located in the site. Two cleaning methods was applied to the harvested plant material: One subset of plant materials was only washed once with deionized water (to mimic the "kitchen style washing") while the second subset was thoroughly cleaned following the laboratory cleaning procedure described in Hettiarachchi *et al.* (2003). Dried and ground plant materials were digested with trace metal grade, concentrated HNO_3 acid (4 hours at 120^{o}C) and the filtered digest solutions were analyzed for trace elements using an ICP-AES or GF-AAS. Soil samples collected at the end of the growing season will be analyzed for various soil parameters including pH, EC and the extractable metals to assess changes in soil chemistry after the growing season. Moreover, Pb bioavailability will be determined with a modified physiologically based extraction test (PBET) to determine the effects of soil amendments (compost).

Results and Discussion

All the sites evaluated so far are located in urban or sub-urban environments. Most commonly found trace element contaminant was Pb. It was apparent from the site history and previous land use that Pb based paint and leaded gasoline could be the most probable sources of Pb in these environments. Out of those sites, the WW site in Kansas City was available for gardening in the summer 2009. Results and discussions are focused on the WW site.

All three soil samples collected from WW site for chlordane analysis showed chlordane concentrations were non-detectable. While analyzing for chlordane, however, it was found that all samples contained detectable amounts of DDT ranging from 0.04 mg/kg to1.3 mg/kg. DDE was detected in two of the submitted samples at 0.03mg/kg and 0.04 mg/kg, respectively. Initial in situ XRF analysis showed elevated levels of Pb in soils. A spatial distribution map of lead levels in soil across the site was prepared from the XRF data (Figure 1). The color scheme employed utilizes dark orange for high concentrations and light orange-yellow for low concentrations. The distribution of Pb was highly heterogeneous and there were several areas of high Pb concentration hotspots scattered thoughout the site. Laboratory results were in close agreement with the in situ XRF analyses and showed elevated lead concentrations of up to 352 mg/kg (Table 1). The soil pH ranged from 6.6 to 7.6 and therefore, no pH adjustments was recommended for this site. Mehlich-3 extractable phosphorous (P) concentrations ranged from 57 mg P/kg (high) to 154 mg P/kg (excessive). Addition of organic matter was recommended for this site (one fourth by volume). Moreover, a variety of methods to reduce any potential risk associated with relatively immobile soil contaminants such as Pb and DDT was recommended to the WW community gardeners. Some of those were: root vegetables should be washed and peeled before consumption; all other vegetables should be thoroughly washed prior to consumption; removal of outer leaves of leafy crops before cleaning.

Table 1. Selected chemical properties of soils collected from the surface 0 to 15 cm (S) and 15 to 30 cm deep (D).

Sample ID	pH[†]	Mehlich-3 P	Available K	Available NH_4-N	NO_3-N	Pb[‡]	OM[§]
		---------- mg/kg ----------					%
9S	6.6	130	624	53.6	73.2	243	3.9
9D	6.6	93	455	9.6	35.1	352	3.4
21S	7.2	116	417	11.8	22.7	117	3.0
21D	7.2	123	221	9.3	15.0	129	3.1
26S	7.8	57	255	8.3	4.3	80	1.5
26D	7.6	80	260	8.2	2.2	60	1.1
39S	6.9	154	488	15.0	24.2	237	4.7
39D	6.9	149	334	9.6	13.3	207	3.3

[†]1:1 Soil: Water
[‡]by 4M HNO_3 acid digestion followed by analysis using ICP-AES
[§] by dry combustion on a LECO CN2000 elemental analyzer

Total soil Pb concentration in the subplots that received compost treatment was lower compared to the subplots that did not receive any compost. This difference can be explained through a dilution effect due to the addition of compost (Table 2) and this would be an added advantage of this treatment in addition to the expected decrease in Pb bioavailability. Concentrations of Pb in Swiss chard (a well known heavy metal accumulator) were far below the maximum permissible level for leafy vegetables in both for no compost and compost added treatments (Table 3). Compost addition reduced the Pb concentrations in Swiss chard ~44 to 49% compared to the no compost treatment. Cleaning method appeared to have some influence on the potential Pb transfer from plants to consumers. Discussions on effects of compost treatments on soil pH, EC, PBET will also be presented. Relationships between plant Pb uptake and extractable Pb will be developed.

Table 2. Lead concentrations in soils, determined by 4M HNO_3 digestion, after compost treatments. Analysis performed on ICP-AES.

Main plot Treatment	Subplot treatment (plant type)	Total Pb concentration (mg/kg)
Compost	Swiss Chard	81.2 ± 4.2†
	Sweet Potato	101.6 ± 16.3
	Tomato	96.5 ± 10.8
No compost	Swiss Chard	95.3 ± 12.6
	Sweet Potato	130.3 ± 10.3
	Tomato	123.1 ± 21.1

† ±standard error of three field replicates

Table 3. Concentration of Pb in Swiss chard (μg/kg, dry weight basis). Analysis performed on GF-AAS.

Main plot treatment	Cleaning method†	Pb concentration (μg/kg)
Compost	Kitchen	311.92 ± 69.67‡
	Lab	259.27 ± 21.83
No compost	Kitchen	523.67 ± 138.43
	Lab	392.87 ± 82.15

† Two cleaning methods was applied to the harvested plant material
‡±standard error of three field replicates

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