Growing crops on urban brownfields: How safe is it?

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Abstract

More and more community gardens are being established on brownfield sites, especially in food deserts in urban cores. While community gardens help to beautify neighborhoods and bring blighted properties back to productive use, a previous survey conducted by Kansas State University indicated that the potential of soil contamination associated with these sites, how to deal with it, and where to get assistance, is often not known. The majority of respondents reported no confidence in their ability to manage soil to mitigate human health risks associated with lead and/or other contaminants. While not all brownfield sites are suitable for growing crops, the majority of sites can be used as gardens after appropriate evaluation and by applying best management practices. In this paper we will provide information on steps to safely garden on an urban brownfield site, including how to get site history information; where, how and what to sample for; resources for soil analyses; understanding soil test results; what to grow in order to avoid uptake of potential contaminants by food crops; and best management practices focusing on reduction of both direct (soil-human) and indirect (soil-plant-human) exposure.

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INTRODUCTION

A brownfields site is a property, the expansion, redevelopment, or reuse of which may be complicated by the presence or potential presence of a hazardous substance, pollutant, or contaminant. In the U.S., approximately 450,000 brownfields sites cover an estimated 4.9 million acres. Since its inception in 1995, the United States Environmental Protection Agency's (US EPA's) Brownfields Program provides funds for assessment and cleanup to bring these sites back to beneficial use. Our work focused on the potential transformation of mildly contaminated brownfields to community gardens. Growing crops on brownfields presents challenges beyond more typical brownfield redevelopment projects because of increased chances of human exposure to contaminants through direct (e.g., soil ingestion) and indirect (e.g., food-chain transfer) exposure. It is also apparent that most of the community gardening groups interested in gardening on brownfields are located in urban areas and many of the brownfields that are candidates for urban gardening are formerly residential properties. Eighty-eight percent of respondents of a survey conducted in 2010-2011 by Kansas State researchers to assess educational needs of urban farmers and gardeners, indicated that they do not have knowledge of the best management practices to minimize health risks involved when growing food crops on soils contaminated with lead, cadmium, arsenic or organic contaminants (Harms et al., 2013). Similar needs and barriers were identified by Kim et al. (2014) from a study conducted in the Baltimore area.

Growing crops on urban brownfields - Questions to ask

We identified the following key questions to be asked before growing crops on urban brownfields.

- Is there contamination?
- If so, what is it and how much?
- Does the site need environmental cleanup? If not, then
- Will crops be grown in-ground or above-ground?
- Who will work in the garden (adults, seniors, children, etc.)
- What are the general soil conditions?
- What crops will be grown?

The following will outline why it is important to ask these questions.

Contamination

Before acquiring a vacant lot to grow on the gardeners need to know the history of the site to identify potential contamination associated with the historic use of the property. This is easily and cheaply accomplished by going to the county courthouse to the registrar of deeds office and looking through the recorded titles/deeds for the property in question, which usually mention the previous use of the property. Other helpful resources are: local historical society (historical aerial photographs and other documentation), Sanborn maps (very detailed historic maps created for fire insurance purposes) found in some local libraries/university libraries or on-line; state environmental department or regional EPA office; and conversations with neighbors and former property owners. Another way to gather historic site information is to hire a title search company or consultant.

If there are environmental concerns based on the historic use of the property, a Phase I environmental site assessment should be performed. These so-called Targeted Brownfields Assessments/Brownfield Targeted Assessments can be performed free of charge by most state environmental agencies or regional EPA offices, but are available only to local government entities or not-for profit organization. Non-eligible gardeners/gardening organizations should work through their local government to have a property assessed. Once the history of the property is known, deductions can be made as to potential associated contaminants. For example, historic use as a service station would point to gasoline/diesel components and possibly heavy metals. Historic residential use may mean that lead from lead-based paint is present in the soil. See for more information (Martin and Hettiarachchi, 2017a, 2017b, and 2017c).

In general, lead (Pb) from the use of leaded paint and gasoline, arsenic (As) from As containing wood preservatives and pesticides are most common and significant contaminants in urban soils. It is well known that the total concentration of trace elemental and other contaminants in the soil environment does not strongly correlate to bioavailability or potential toxicity (Henry et al., 2015; Hettiarachchi and Pierzynski, 2004; Traina and Laperche, 1999). Bioavailability of a contaminant depends on the contaminant's chemistry and the soil properties present. 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, if necessary.

Resources for gardeners for contaminant testing (Martin and Hettiarachchi, 2017c):

- State environmental agency or regional EPA office (free sampling/testing for contaminants; not-for-profits and local government)
- Local government (free testing for contaminants, if the local government has an EPA brownfields assessment grant or requests assistance from the State or EPA)
- Local health department (some health departments can screen for soil Pb via XRF)
- Agricultural Extension Services (for metals only - not all extension services offer this-, small fee)
- Environmental laboratories (charge for services)
- Environmental consultants (charge for services)

Soil conditions

In most cases, soil contamination is not the main issue. There can be multiple common soil quality issues associated with brownfield sites:

- Poor nutrient status

- Soil pH – too low or too high
- Lack of organic matter
- Soil type (clayey or sandy soils) not suitable for growing crops
- Soil Compaction
- Other soil chemical issues – such as excess sodium, excess salts

Therefore, in addition to environmental testing for potential contaminants, soils need to be tested for various agronomic parameters to determine their suitability for growing crops. Some major soil properties to be tested are: soil pH, soil organic matter (soil organic carbon), available macro- and micronutrients. Soils can get tested through commercial labs or USDA Cooperative Extension System (land grant universities) soil labs. For additional information on soil sampling, testing and a list of soil test laboratories available in various states see Martin and Hettiarachchi 2017d. The local extension office or state extension program will be able to help with test interpretation if tests were done outside laboratories (e.g., Upham, 2018).

Soil sampling

The sampling method is usually dictated by available historic property information, area to be covered, and available budget. A few different approaches can be considered:

- Sample selectively – based on site history research and current conditions
- Sample systematically – grid pattern. This approach is chosen when there are no indications from the environmental assessment/records search/general site conditions as to the location of potential contaminants. This method requires the most samples and is therefore the costliest one.
- Sample randomly – this approach is chosen when there are no indications for selective sampling and the sampling budget does not allow for systematic sampling.

Start out at a few key locations for future garden beds and expand the sampling area based on the analytical results, if necessary.

Regardless of the method, gardeners usually prepare composite samples for analysis as cost can become prohibitive, especially when sampling for environmental contaminants. While compositing is a good approach when sampling large areas, it needs to be recognized that small, localized areas of potential contamination may be missed as the analytical result will provide an average concentration over the large area, instead of a specific concentration for a specific location.

What crops will be grown?

Sampling depths should be dictated by the rooting depths of the crops to be grown. Lettuce, for example, has a much shallower rooting depth than tomatoes. If multiple crops with varying rooting depth are to be grown in an area, sampling depths should cover the entire rooting interval. Sampling depths from land surface to 12 inches below land surface are usually sufficient to cover the rooting depth of most crops grown under ideal conditions. It should be noted that dry conditions will force crops to root deeper than their normal rooting depth in search of moisture.

In-ground vs above-ground growing

The decision to grow in-ground versus above-ground depends on many factors such as:(1) liability- because of perceived contamination issues, gardeners may stay away from growing in-ground, cities may discourage growing in-ground on city owned properties, (2) the comfort level of gardeners regarding residual contamination- although science/research clearly shows it is safe, some gardeners may not feel comfortable to grow in-ground, (3) soil conditions- some soils may not be suitable for growing crops due to high clay content, compaction, and other soil quality issues,

(4) accessibility- some gardeners (seniors) may prefer raised beds due to accessibility, (5) cost- raised beds could be cost-prohibitive, and (6) space- installation of raised beds may reduce the space available for gardening.

Our project

We evaluated seven sites throughout the U.S.A. as part of our project (Figure 1). Two of them are discussed below as examples (Picture 1). The site in Kansas City, Missouri was in a residential neighborhood. This site was approximately 138 ft x 121 ft and was formerly occupied by four residences. The Tacoma, Washington, site was located on a church property and covered an area of approximately 141 ft x 79 ft. Both sites were screened for trace elements using a XL3T Niton hand-held x-ray fluorescence analyzer. Screening locations were established by using a 10 feet grid system to facilitate generating spatial distribution maps of trace elements of interest. Soil samples were also collected for laboratory confirmation analysis. Soil chemical properties (available N, P, and K, pH, electrical conductivity, organic C, and total trace elemental concentration in soils) were determined using appropriate procedures (Sparks et al., 2005).

The basic experimental design at both sites was a split plot design with four replications. At the Kansas City and Tacoma sites, the main plot factor was compost treatment (2 levels, no compost or compost added). At the Tacoma site, a Tagro mix (a blend of 50 percent biosolids, 25 percent sawdust and 25 percent screened sand) was used as the compost material. Swiss chard, carrots and tomatoes were grown at the Kansas City site, while carrots, tomatos, and lettuce were grown at the Tacoma site. The subplot factor was the cleaning method of the harvested produce. Cleaning procedures adopted were “kitchen style washing” and laboratory cleaning. Dried and ground plant materials were digested with concentrated HNO_3 acid in a microwave digestion unit and analyzed for trace elements using GF-AAS. Bioaccessible Pb in soils was determined with a modified physiologically based extraction test (PBET) (Ruby et al., 1996; Attanayake et al., 2014; Defoe et al., 2014).

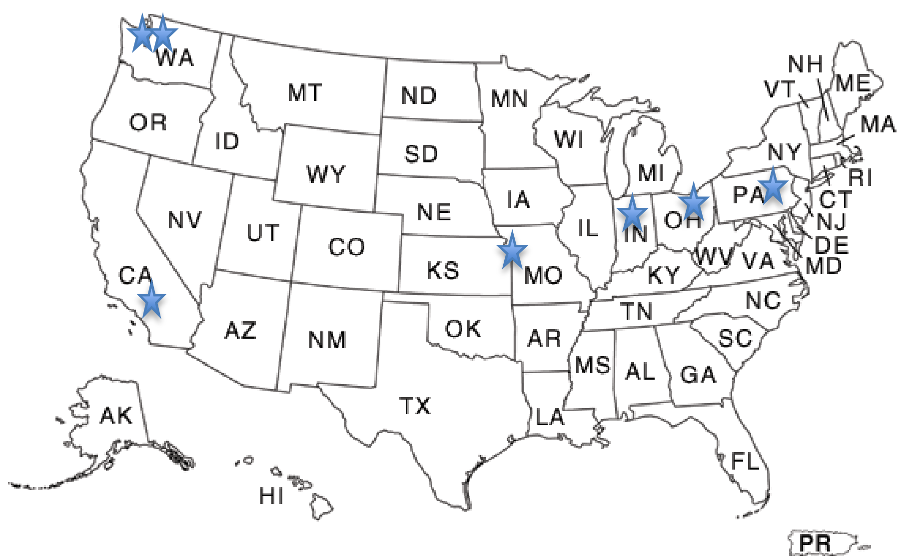

Figure 1: Project test sites for evaluating the safety of growing food crops on brownfield sites.

Picture 1. Kansas City and Tacoma test plots, summer 2010. Tacoma sub plots that received Tagro+dolomite showed significantly more biomass than the control.

Kansas City site:

The distribution of Pb in soils was highly heterogeneous and ranged from 60 to 352 mg/kg. Soil pH ranged from 6.6 to 7.6 and Mehlich-3 extractable phosphorous (P) concentrations ranged from 57 mg P/kg (high) to 154 mg P/kg (excessive). The total soil Pb concentration in the subplots that received compost treatment was lower compared to the subplots that did not receive any compost and this can be attributed to the dilution effect due to compost addition (Table 1).

The treatment effect (compost addition) was significant for Pb concentrations in swiss chard and carrots but not for tomatoes ($p<0.05$). Most probably Pb concentrations in tomatoes were not high enough to show any concentration differences due to compost treatment. For tomatoes and swiss chard laboratory cleaned samples had significantly ($p<0.05$) lower Pb concentrations compared to the Pb concentrations found after kitchen style cleaning. Cleaning methods were not significant for Pb concentrations in carrots. The bioaccessible Pb concentrations as measured by PBET in soils were not significantly different between compost added and no composts added soils.

Table 1. Lead concentrations in soils and plants, Kansas City, MO site.

Main Treatment	Plant	Soil Pb (mg/kg or ppm)	Plant Pb¶ (µg/kg or ppb)
Compost	Swiss chard	155±35†	289±42
	Carrot	129±11	1406±234
	Tomato	154±15	64±17
No compost	Swiss chard	221±48	705±84
	Carrot	224±55	1369±179
	Tomato	189±28	88±29

†±standard error of four field replicates.

¶Concentration pf Pb in lab cleaned samples. ML, Maximum allowable levels: leafy vegetables, 0.3 mg kg−1 fresh weight; fruiting vegetables, root and tuber crops, 0.1 mg kg−1 fresh weight (FAO/WHO-CODEX, 1995; 2010 amendment). Swiss chard ML = 5.0 mg kg−1 dry weight (DW); moisture content 94%. Tomato ML = 1.6 mg kg−1 DW; moisture content 94%. Carrot in 2010; ML = 1.5 mg kg−1 DW, moisture content 93%.

Table 2. In vivo physiologically based extracted test Pb in soils, at 2.5 pH adjustment (Attanayake et al., 2014).

Treatment	pH 2.5	
	Pb (mg/kg)	Pb % †
Compost	9±1 ‡	6±0
No compost	13±7	6±2

† Physiologically based extracted Pb as a % of total Pb.
‡±standard error of four field replicates.

Tacoma site:

Soil As and Pb concentrations ranged from 8 to 162 and 17 to 427 mg/kg, respectively while soil pH ranged from 5.0 to 6.0. Lead uptake data followed the same trends as presented above for Kansas City site. Arsenic concentration in all three vegetable types were low. Arsenic concentrations in lettuce and tomatoes grown with added Tagro+dolomite were smaller than those grown without these amendments (Table 3). Increased biomass production when Tagro was added is the most likely reason for the reduced As concentration observed in lettuce and tomatoes (Defoe et al., 2014). The bioaccessible As concentrations in soils as measured by PBET were low (Table 4).

Table 3. Arsenic concentrations in soils and plant samples, Tacoma, WA site.

Main Treatment	Plant	Soil As (mg/kg or ppm)	Plant As¶ (μg/kg or ppb)
Tagro+dolomite	Lettuce	88.3±14.7	81.2±11.5
	Carrot	77.6±5.3	181.9±27.6
	Tomato	57.7±9.7	39.7±10.8
Control	Lettuce	85.9±20.7	151.0±28.6
	Carrot	81.9±19.9	144.2±43.2
	Tomato	84.9±6.3	101.0±11.6

†±standard error of four field replicates.
¶ For As in vegetable there are no established maximum levels. We can use a conservative maximum level of 750-1800 mg kg^{-1} calculated based on the Integrated Risk Information System (USEPA, 1993) lists inorganic As reference dose level of 0.0003 mg kg^{-1} d^{-1} (Defoe et al. 2014).

Table 4. In vivo physiologically based extracted test As in soils, at 2.5 pH adjustment (Defoe et al., 2014).

Treatment	pH 2.5	
	As (mg/kg)	As % †
Compost	5.5 ‡	6.9
No compost	5.1	6.6

† Physiologically based extracted As as a % of total As.
‡±standard error of four field replicates.

SUMMARY

The most common soil contaminant at the brownfields sites in our project was lead. We also found elevated arsenic and polycyclic aromatic hydrocarbons at one or more of our test sites. Our research indicates that the potential exposure pathway of concern is direct exposure of humans to contaminated soils. The pathway from contaminated soil to plant to human is insignificant. Our research has shown that, in general, concentrations of lead, arsenic and polycyclic aromatic hydrocarbons in vegetables harvested at test sites were low and contaminants can be diluted by the addition of clean compost. Compost additions help reduce contaminant concentrations in vegetables and also reduce bioaccessible lead and arsenic (measured by modified PBET developed by Ruby et al. 1996). Root crops (such as carrot, radish, beet, etc.) tend to accumulate lead but not arsenic. Based on our research we recommend that, if in doubt regarding potential soil contaminants and their respective concentrations, growing root crops directly in-ground should be avoided. We recommend soil testing and using common sense measures, such as washing crops thoroughly prior to consumption to get rid of adhering soil particles, washing hands thoroughly after gardening, using a mulch to cover bare soil, keeping soil moist during dry and windy conditions to prevent dust generation and making sure no soil gets tracked into the house on shoes and/or clothing, and supervising children in the garden, as effective and preventative measures to ensure safe gardening/growing.

Additional resources for urban gardeners

https://www.epa.gov/brownfields/turning-brownfields-community-supported-and-urban-agriculture
https://www.gardeningonbrownfields.org/
https://www.nrcs.usda.gov/wps/portal/nrcs/main/national/programs/financial/eqip/

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