


Trace Metal Content of Community Garden Soils and Plants in Metropolitan Phoenix, AZ

Report prepared for a collective of metro Phoenix community gardens

June 2018

Arizona State University

Central Arizona-Phoenix Long-Term Ecological Research
CAP LTER

Acknowledgements

This report was prepared by:

Caitlin Holmes, New Mexico State University, Las Cruces, NM
Sharon J. Hall, Ph.D., School of Life Sciences, Arizona State University, Tempe, AZ
Hannah Heavenrich, M.S., School of Life Sciences, Arizona State University, Tempe, AZ
Everett Shock, Ph.D., School of Molecular Sciences, and Earth and Space Exploration, Arizona State University, Tempe, AZ

This research was funded by the Central Arizona–Phoenix Long-term Ecological Research project, grant No. DEB-1026865, and the ASU School of Sustainability.This project was inspired and made possible by our five local community garden partners.

Table of contents

List of tables

List of figures

Acronyms

ATSDR	Agency for Toxic Substances and Disease Registry
AZDEQ	Arizona Department of Environmental Quality
EPA	Environmental Protection Agency
ESCA	Ecological Survey of Central Arizona
EU	European Union
IRIS	Integrated Risk Information System
NRCS	Natural Resource Conservation Service
NYS DEC	New York State Department of Environmental Conservation
OEHHA	California Office of Environmental Health Hazard Assessment
OSHA	Occupational Safety & Health Administration
USDA	United States Department of Agriculture

Executive summary

Community gardens provide multiple ecosystem services for people and the environment. These practical spaces produce food, reintroduce a natural aesthetic into metropolitan areas, and can support the local economy. Nonetheless, there are health risks associated with consuming foods grown in urban soils. Recent studies in cities across the world show that plant uptake of heavy metals from soil is highest among leafy greens, which are some of the most common products of community gardens. Furthermore, the extent of soil pollution is proportionate to the distance from various sources, such as buildings, industrial sites, and roadways. However, few studies have compared patterns of soil contaminant distribution and uptake at citywide scales, or compared metal concentrations between leafy greens that were grown in community gardens and commercial agricultural fields. Additionally, few studies have been conducted on community garden soils in arid or semi-arid cities where dryland soil properties may affect pollutant exposure.

In this study, we examined the concentration of lead (Pb) and cadmium (Cd) in soil and leafy green vegetables in five community gardens within metropolitan Phoenix, AZ, a city of 4 million people located in the northern Sonoran Desert. In addition, we compared the heavy metal content of soil, store-bought spinach, and community garden leafy greens (mixed kale and spinach) relative to state, federal, and international health limits.

Findings:

- Pb content of soil from Phoenix-area community gardens ranged from 28.8 to 238.2 mg Pb/kg. Soil Cd content ranged from 0.6 to 8.9 mg Cd/kg. Mean Pb and Cd concentrations were below the guidelines set for residential soil by the US Environmental Protection Agency (EPA). A few gardens were above the limits set by California. Based on limited sampling of 5 locations, soil metal content in community gardens was not significantly related to regional patterns of soil metal content across the metro area. However, further research is necessary to confirm this pattern.
- Pb content of leafy green vegetables grown in community gardens ranged from undetectable to 0.28 mg Pb/kg fresh weight, while plant Cd ranged from 0.01 to 0.18 mg Cd/kg fresh weight. Garden leafy green Pb and Cd concentrations are at or below the maximum recommended limit based on international (EU) guidelines.
- Pb content of conventional spinach from grocery stores was undetectable. Cd content of conventional spinach ranged from 0.3 to 0.4 mg Cd/kg fresh weight, which is above the EU limits.
- Plant and surface soil Pb concentrations were not significantly related to soil organic matter, soil texture, or pH. Plant Cd concentration was negatively correlated with sand. Soil Pb concentration was significantly correlated with soil Cd.

- Soil metal content was not significantly different between bed types (raised beds or in-ground beds), although we tested this trend in only one garden.
- Soil Pb and Cd content was also not significantly different between surface samples (0-15 cm) and deeper samples taken from the same soil pit (15-30 cm) in raised beds.

Recommendations

As a result of the moderate content of heavy metals in sampled soils of some Phoenix-area community gardens, future efforts should consider the location of new gardens relative to known soil Pb and Cd hotspots, and test the metal content of in-ground and imported soil or compost. Community gardens can improve their soils and limit heavy metal uptake by plants by adding organic matter (low-metal compost) and building raised beds with contaminant-free wood or other contaminant-free containers.

1. Introduction

Community gardens have become popular due to their numerous social and economic benefits. These common spaces produce affordable, nutrient-rich food for community members and encourage healthier eating habits for residents, among other benefits (Table 1; Holmer 2011, Ghose and Pettygrove 2014). Additionally, community gardens create a suite of ecological services. For example, open spaces with vegetation in cities provide a habitat for diverse fauna, such as honeybees, whose populations are diminished through land fragmentation and pesticide use in commercial agricultural landscapes (Dunnett and Qasim 2000, Samnegard et al. 2011). Furthermore, vegetated gardens can alleviate flooding by promoting water infiltration when they replace hard surfaces, cool neighborhoods by increasing shade and evapotranspiration, and absorb carbon to partially offset emissions from human activities (Cameron et al. 2012).

Table 1. The benefits of community gardens.

Physical	Outdoor activities	Holmer 2011
Economic	Affordable and nutrient rich food	Ghose and Pettygrove 2014
Social	Community participation, environmental education	Ghose and Pettygrove 2014, Holmer 2011
Ecological	Habitat for fauna, flood and urban heat mitigation, carbon sequestration	Samnegard et al. 2011, Dunnett and Qasim 2000, Cameron et al. 2012

Despite the widespread benefits offered by establishing gardens close to where people live, urban and suburban gardens that produce edible crops are at risk of heavy metal contamination from prior commercial agricultural or industrial land uses, or exposure to pollutants from gasoline, paint, or blowing soil (Hibben et al. 1984, Stilwell et al. 2008, Kim et al. 2015). Humans are primarily exposed to these environmental contaminants through soil ingestion (by infants and toddlers), inhalation of soil particles, and consumption of plant and animal products that are grown in contaminated soils (Islam et al. 2007).

The form (compound), concentration, and relationship to other heavy metals are factors that determine the potential for toxic accumulation in people. Federal guidelines from the Food and Drug Administration (FDA) and the Environmental Protection Agency (EPA) state that people should consume no more than 0.001 mg Cd/kg body weight per day and 6 micrograms (µg) Pb per day (children) because these metals accumulate in the body, and at toxic levels they can cause nerve damage, heart disease, abnormal kidney function, renal failure, and liver failure (US EPA IRIS 1985, Satarug et al. 2000, Satarug and Moore 2004, FDA 2017).

Densely populated, low-income communities are generally at greater risk of exposure to contamination sources (Zhuo et al. 2012). The availability of low cost housing or job opportunities that do not require advanced education are typically located in areas of poor environmental quality (Pulido 2000). Large land vacancies in these neighborhoods—in part from demolished buildings—are appealing to garden enthusiasts, local people, schools, and community centers who wish to increase community access to nutritious food sources (EPA 2011b). However, growing food in abandoned lots to feed residents of adjacent neighborhoods could be detrimental to these communities if the gardens are contaminated from their previous land use (Ghose and Pettygrove 2014).

Food insecurity is a major issue for low-income communities, including people in greater Phoenix, a metropolitan area of 4 million people in central Arizona. In 2014, metropolitan Phoenix contained 55 food deserts, defined as residential areas that are located greater than a mile from a grocery store (Ver Ploeg et al. 2011, Lasch 2012). Of the number of inhabitants in Phoenix, 12% meet the state poverty guidelines for the average number of individuals living in one residency (HHS 2014). Due to food insecurity in the city, the USDA classified all of the downtown Phoenix area as a food desert, and nearly 57% of the Maricopa County population has limited access to grocery stores (Lasch 2012, Fitzpatrick 2013, ERS 2015).

Community gardens could facilitate access to an inexpensive source of food and promote a healthier lifestyle for people who would not otherwise be able to afford or have access to nutritious foods. Recently, communities have been empowered to expand the number of food sources by transforming abandoned fields, former brownsites, old parking lots, backyards, or otherwise empty spaces into productive gardens. However, to best achieve community health goals, it is important to consider where gardens are established in the event these reconstructed sites contain high levels of contaminants in the soil.

2. Background on heavy metals

Sources

Heavy metals are naturally found in mineral compounds and soils, and in some forms are available for plant uptake. In the continental United States, concentrations of heavy metals in undisturbed soil range from 7-700 mg Pb/kg dry soil and 1-10 mg Cd/kg dry soil (Shacklette and Boerngen 1984). Concentrations of these metals in urban soils in Phoenix range from 20 to 193 mg/kg for Pb, and less than 1 to 9 mg/kg for Cd (Zhuo 2010). Although certain metals are necessary to sustain life, prolonged exposure can increase the vulnerability of biological systems to toxic levels of accumulation.

Toxic heavy metals are metals or metal compounds that, when consumed in large amounts over time, have adverse health effects (Goyer 1995). One of these, cadmium (Cd), is generally found in zinc ores and is used in the production of rechargeable batteries, alloys, solar cells, and pigments. Cd is also concentrated in agricultural superphosphate fertilizers, which can contain as much as 300 mg Cd/kg of fertilizer (ATSDR 2012, Naveedullah et al. 2013). Although relatively harmless when it is in its immobilized ore form, the ingestion and inhalation of large doses of free, mobilized Cd over long periods of time is known to be carcinogenic (ATSDR 2012). Lead (Pb) also occurs at low concentration naturally in Earth's crust. When mined and concentrated, it becomes useful in the production of alloys, cable coverings, ammunition, tires, pipes, paint, and gasoline additives (Huisingh 1974, Chaney et al. 1984, Colbourn and Thornton 2006, OSHA 2014). Primary sources of Pb exposure for humans are food, water, air (from the inhalation of dust particles), industrial work, and decaying house paint, which commonly contained Pb before the 1970's (Lazrus et al. 1970, Lanphear et al. 1998). Sources of heavy metals in community areas include natural sources, but anthropogenic sources are likely the leading cause of toxic heavy metal content in community garden soils (Salvagio Manta et al. 2002, Hettiarachchi and Pierzynski 2004).

State, federal, and international guidelines

Gardeners are aware of the problems associated with heavy metal contamination of soil, but, to date, food that is produced in community gardens is not required to be tested for heavy metal content (ATSDR 2007, 2012, Sowerwine et al. 2018). Furthermore, few garden soils are tested due to lack of funding for soil analyses and lack of expertise to interpret scientific findings from commercial soil testing laboratories (Gublo 2015). Based on current EPA guidelines, soil from residential landscapes that contain less than 400 mg Pb/kg of soil and 70 mg Cd/kg are considered safe for growing produce (Table 2; US EPA 2001, 2018). However, a 2014 technical working group of the EPA advised that soil with Pb concentrations >100 mg/kg are of potential concern for gardening (US EPA 2014). Some states in the U.S. have more strict soil guidelines for food production in residential areas, including Connecticut, California, and New York (Table 2; AZDEQ 1991, NY DEC 2006, CT DPH 2014) The California Office of Environmental Health Hazard Assessment recommends a maximum limit of 80 mg Pb/kg and 1.7 mg Cd/kg for residential soils based on risks to human health (CalEPA OEHHA 2009). The Ministry of Environment of Finland, as reported in Carlon et al. 2007 and Toth et al. 2016, advises additional assessment of the area for topsoil exceeding 60 mg/kg Pb and 1 mg/kg Cd.

In addition to the guidelines for soil heavy metal content, some agencies have set maximum limits for food (e.g. the European Union) or the daily ingestion of Pb and Cd by people (Table 2; EC 2006, Mushak 2011). Community gardens are not required to test soils for contamination, and if testing is done and contamination is reported, gardens are not required to remediate soils (Sowerwine et al. 2018). In contrast, commercial growers are required to test fertilizers and biosolids (manure, sewage sludge) prior to its application on agricultural plots, although plants produced from commercial agriculture do not require testing for metal content (US EPA 1993).

Table 2. Soil and plant Pb and Cd limits for growing food.

	Food				Soils			
Recommender	Pb	Cd	Units	Source and Notes	Pb	Cd	Units	Source and Notes
EU	0.3	0.2	mg/kg fresh weight leaf vegetables	EC (2006)	60	1	mg/kg	These are 'threshold' values, which indicate the need for further assessment of the area, as defined by the Ministry of Environment of Finland, per Toth et al. (2016); Carlon et al. (2007).
US FDA (food) or EPA (soil)	0.1-1.7	0.001	Pb (ppm), Cd (mg/kg/day)	FDA has issued limits only for certain foods (water, juice, candy, shellfish), Mushak 2011; Cd: US EPA IRIS (1985)	400	70	mg/kg	EPA (2001, 2018)
US EPA TRW	--	--		--	100	--	mg/kg	Potential risk; EPA TRW (2014)
CA	--	--		--	80	1.7	mg/kg	CalEPA OEHHA (2009)
CT	--	--		--	100	1	mg/kg	Use caution for soil samples above these limits; CT DPH (2014)
AZ	--	--		--	400, 700, 4	100, 10, 1	mg/kg	Health based guidance level for ingestion of soil; soil cleanup levels; Worst case i.e. ingestion; AZDEQ (1991)
NY	--	--		--	400	2.5	mg/kg	NYS DEC (2006)

Factors related to heavy metal bioavailability

Crop uptake of heavy metals is a major pathway of exposure for humans who consume food produced in contaminated soils. Factors that affect the potential bio-availability of heavy metals include soil acidity, texture, and organic matter content; plant species; and the metal's elemental form (Huisingh 1974, Chaney et al. 1984, Chuan et al. 1996). Phytoavailability, or the amount of heavy metals available for plant uptake, is dependent on the solubility of soil Pb and Cd (Hettiarachchi and Pierzynski 2004). Stable, insoluble compounds are less likely to be absorbed by plant roots and are unlikely to be assimilated through plant ingestion by humans. Soil acidity (low soil pH) increases the solubility of heavy metals, making them more available for plant uptake (Singh et al. 1995, Angima and Sullivan 2008). Because metal ions exhibit positive (+) charges, acidic soils will facilitate the mobilization of heavy metals by inhibiting metal binding to soil particles (NRCS 2000, Angima and Sullivan 2008).

Soil texture and organic matter also affect the bioavailability of heavy metals. Fine-textured soils with high clay content have more binding sites for heavy metal ion adhesion than larger-grain textured soils like sand. Heavy metals do not bind to larger-grain particles in soil, thus enabling their mobilization and potential uptake by plants (McLean and Bledsoe 1992, Clark et al. 2008). Soil organic matter is also known to bind heavy metals so that they become insoluble, and is thus used extensively to remediate agricultural soils (Prasad 2002).

Vegetables that have extensive contact with soil, such as leafy greens and root vegetables, are especially vulnerable to the accumulation of mobilized heavy metals (Spittler and Feder 1979, Chaney et al. 1984). The efficiency by which plants can accumulate heavy metals is related to plant organ and tissue structure, where a high root to shoot ratio increases the uptake of toxins (Spittler and Feder 1979, Islam et al. 2007). Leafy green crops tend to be more susceptible to metal contamination compared to other types of crops because of their fast growth rates and broad leaf areas that accumulate dust (Spittler and Feder 1979, Finster et al. 2004, Chang et al. 2013).

3. Methods

In this study, we quantified Cd and Pb content in soils and leafy greens from five community gardens and compared our results with regional patterns of soil Cd and Pb across the Phoenix area. A previous city-wide analysis of soil metals was conducted at 200 locations in the 2000 Ecological Survey of Central Arizona (ESCA), as a part of the Central Arizona–Phoenix Long-term Ecological Research Project (Zhuo and Shock 2010, Zhuo et al. 2012). This survey showed an uneven distribution of soil Pb and Cd across the Phoenix metro area, with high concentrations in areas of former agricultural and urban use (Zhuo 2010, Zhuo et al. 2012). We expected soil metal content of community gardens to follow this larger, city-wide pattern. We also expected that soil from elevated, raised beds would contain less Pb and Cd than the non-raised beds that are located in the ground (McLean and Bledsoe 1992, Clark et al. 2008, CDPH 2014). Finally, we expected there would be no difference in metal content between shallow (0-15 cm) and deeper soils (15-30 cm) within raised beds. Growing plants in raised beds can limit root contact with potentially contaminated pre-existing soil.

In addition to examining soil contamination, we investigated the metal content of leafy greens in our five study gardens to determine if it was related to the metal content of the soil in which the plants were grown. Because soil metal content in the ESCA city-wide survey was below the recommended EPA guidelines for health concerns, and because metal content in plants can reflect how much metal is found in the soil (Toth et al. 2016), we expected that the heavy metal content for leafy greens grown in community gardens would not exceed the existing guidelines for ingestion (from the European Union; 0.3 mg Pb/kg fresh weight and 0.2 mg Cd/kg fresh weight). EPA guidelines for ingestion of heavy metals in foods do not currently exist.

Site description

In September 2014, we contacted gardens in the Phoenix metropolitan area that aim to combat food insecurity and economic marginalization issues in their communities. Among these, five different community gardens agreed to participate in this study. The gardens vary in location across the metro area, in age, size, and structure; and community members utilize a variety of growing techniques, such as importing soils, building raised beds, and using compost and irrigation to enhance productivity. For privacy, garden names are not disclosed (Table 3).

Table 3. Community garden characteristics and sampling design.

Garden Number	Soil source	Former land use	Number of soil samples* analyzed from each bed type: Raised	In-ground
1	Local (on-site) and donated from the city	Abandoned field, public dumping site	2	2
2	Local (on-site) and donated from the city	Agriculture	6	None
3	Local (on-site), compost, and donated from the city	Agriculture, industrial	6	3
4	Compost, and donated from the city	Agriculture, city park	4	None
5	Local (on-site) and compost	Agriculture, residential	4	1

*Soil samples are composed of two homogenized soil cores.

Experimental design

In each garden, we sampled from planting bed types that were used specifically to grow leafy greens. In some gardens, these sampling locations were raised beds, in which soil was elevated and contained by a wall such as wood or recycled car tires (hereafter, called ‘Raised’ beds; Fig. 1). In other locations, leafy greens were grown using in-ground beds, where soil was not bounded or raised (hereafter called ‘In-ground’ beds; Fig. 1). In many gardens, only one bed per category (i.e. Raised or In-ground) grew leafy greens. In the case where there were multiple raised or in-ground beds growing leafy greens within a garden, we randomly chose beds and sampled soils and plants in each (i.e. some gardens have two or three replicate soil samples of plants or soil in Raised or In-ground beds).

Soil and plant sample collection

For each soil sample, we collected two separate soil cores using a slide hammer core from 0 to 15 cm depth and another two from 15 to 30 cm depth, with cores located at least 50 cm apart from one another. The two cores from each sampling location and depth were then combined into a single plastic bag and homogenized to compose one soil sample to be analyzed. From each of our five gardens, we collected and analyzed at least one homogenized soil sample (composed of two soil cores each) from each bed type that was present at that location (Fig. 1; Table 3). In sum, we analyzed 2-6 soil samples from each of five community gardens. Out of the 28 soil samples analyzed, 17 were collected from 0-15 cm depth, and 11 were collected from 15-30 cm depth.

In addition to soil samples, we took three samples of leafy greens that were growing in each garden and bed type, where possible. These plant samples came from *Cavalo nero* (kale) or *Spinacia oleracea* (spinach), both of which were present in most gardens. At each site, one leaf from each of two-three individual plants was randomly chosen for sampling. Inner leaves were chosen by gently pulling back an outer leaf and then, using scissors, cutting the next available leaf approximately 2 cm from the stem of the plant.

To compare metal concentrations between our sampled leafy green plants and leafy green plants commonly sold in grocery stores, we purchased one bunch of conventional spinach from each of three separate grocery stores – Sprouts, Safeway, and Food City – in the Phoenix metropolitan area in March of 2015. We sampled and analyzed 3 leaves each from 3 conventional spinach bunches. Leaves were clipped above the stem, and the 3 leaves of each bunch combined in a bag prior to processing.

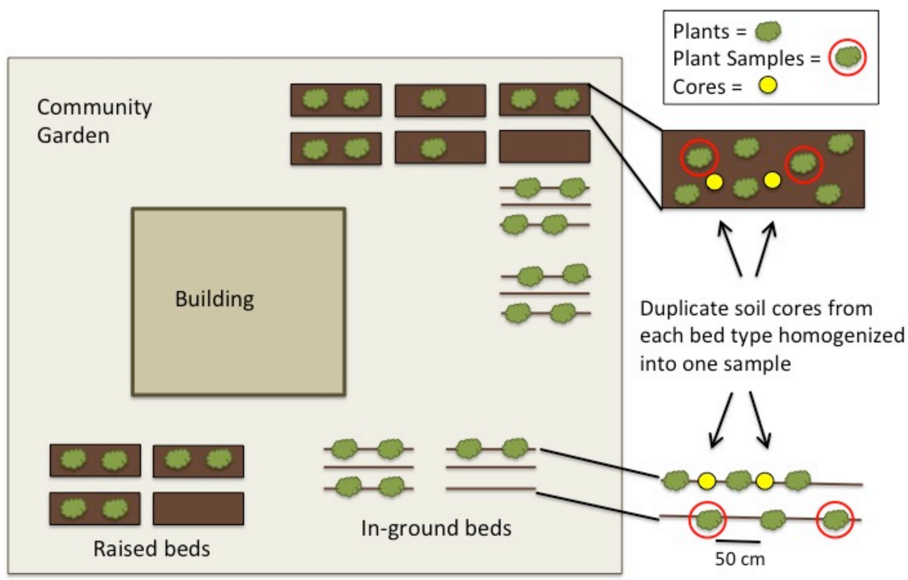


Figure 1. Generalized layout of community gardens used in this study, including plant and soil sampling locations.

Soil and plant sample preparation and metal analysis

We sieved soils to 2 mm prior to analyses. All plant leaves were rinsed thoroughly using tap water to replicate average consumer habits. We then placed both soils and plant samples in a 105°F oven to dry overnight. Once dried, we pulverized each sample into fine powder using a ball mill at the Goldwater Environmental Laboratory at ASU.

We measured soil Pb and Cd content on plant and soil samples using standard EPA methods for soil trace metals (EPA 1996). We first digested about 0.25 g each of dried soil and plants in a solution of HNO_3, HF, and $HBrO_3$ to dissolve the soil and plant material prior to analyses. We then diluted the samples and used inductively coupled plasma optical emission spectrometry (ICP-OES) to determine metal concentrations. The detection limit for our analyses was 0.001-0.01 mg/kg of soil or plant material for Pb and <0.0001 mg/kg for Cd.

We did not complete a full spectral analysis of other metals in the soil samples, although this method would have controlled for interactions that other metals may have with metals of interest (Cd and Pb).

Analysis of soil characteristics

In addition to metal analysis, on each soil sample we measured a suite of soil properties that can affect metal solubility, including texture (particle size analysis), pH (a measure of acidity or alkalinity), and organic matter content.

Soil texture analysis. Soil particle size, or texture, influences soil porosity, water holding capacity, and how metals move through soil. We determined soil texture by using a modified hydrometer method (Bouyoucos 1962), which estimates the soil content (in %) of sand (2.0-0.05 mm diameter particles), silt (0.05-0.002 mm), and clay (<0.002 mm) (Gee and Bauder 1986). We shook a solution of 40 g of oven-dried soil with 100 mL of a sodium hexametaphosphate solution to prepare the samples for analyses. After shaking, we put each sample in a 1-L suspension cylinder and filled the cylinder to a 1-L mark with deionized water. We used a mixing rod to mix the sample until it was homogenized within the cylinder, then we placed the hydrometer into the sample. After 40 additional seconds of no mixing, we recorded the hydrometer reading. We took hydrometer readings on each sample at 40 seconds to determine the combined percent silt and clay content and 7 hours to determine the percent clay content. We subtracted the clay content from the clay plus silt content to determine percent silt, and we determined percent sand content by subtracting the percent silt plus clay from 100%.

Soil pH and organic matter analysis. Soil pH was assessed using a modified EPA method (Ghose and Pettygrove 2014). We shook approximately 15 g of soil in 30 ml of deionized (DI) water for 30 minutes, and then used a calibrated pH meter to read the pH of each sample. Percent soil organic matter was determined using a modified loss on ignition (LOI) method (Schulte and Hopkins 1996). We placed 20 g of oven dried soil samples in a 550°C furnace for 6 hours and measured the loss of mass to determine organic matter percentage.

Data analysis

All soil data are presented in units of mg Pb or Cd/kg dry soil, and all plant data are presented in units of mg Pb or Cd/kg fresh weight. Fresh weight of plant samples was determined based on a 90% moisture content of leafy greens (EPA 2011a). We tested whether soil or plant metal content was higher than health screening levels using one-tailed t-tests for soil metal content (compared to CA limits) and plant metal content (compared to EU limits). Additionally, we compared soil Pb and Cd content from in-ground and raised beds at Garden 3 using non-parametric Mann Whitney U tests. We explored the relationship between soil metal content and soil depth in raised beds of four gardens (2, 3, 4, and 5) using a linear mixed effects model with soil metal content as the dependent variable, soil depth as the independent variable, and garden number as a random factor. We compared soil and plant metal content with soil characteristics using bivariate Pearson correlation tests. Finally, to test whether garden soil and plant metal content was related to city-wide patterns, we compared our samples to interpolated/kriged 0-15 cm depth Pb and Cd data from Zhuo (2010) based on our five community garden locations using kriging in ESRI Arcmap. We used a kriging procedure on the Zhuo 2010 dataset to average all data within a 5 km radius of each garden location. All dependent variables were log-transformed as necessary to satisfy linear model assumptions of normality and homoskedasticity.

4. Results

Soil Pb and Cd content varied significantly across the five gardens sampled in this study (Figure 2, Table 4). Average soil Pb was statistically higher than the California health screening level only in garden 3 (one-tailed t-test with 80 mg Pb/kg as the standard), but individual samples from gardens 2, 3, and 5 also exceeded this value. Average soil Cd from was statistically above the California screening level only in garden 5 (one-tailed t-test with 1.7 mg Cd/kg as the standard), although individual soil samples from gardens 2, 3, and 5 exceeded this value.

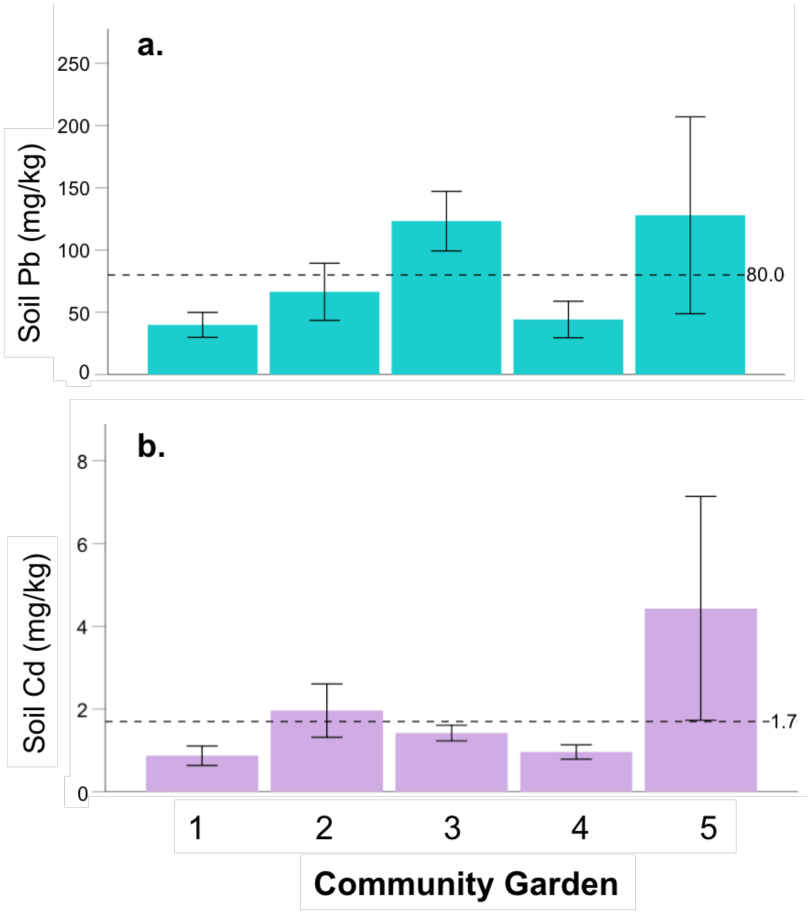


Figure 2. (a) Soil Pb concentration (mg/kg) and (b) Soil Cd concentration (mg/kg) from community gardens in metro Phoenix. Error bars are +/- 1 standard deviation. Reference lines are shown for the California human health screening level for soil Pb (80 mg/kg), and soil Cd (1.7 mg/kg).

Table 4. Soil and leafy green Pb and Cd content from community gardens in metro Phoenix. SD = standard deviation; *N* = number of samples analyzed.

	Soil Pb (mg/kg)					Soil Cd (mg/kg)					Plant Pb (mg/kg fresh weight)					Plant Cd (mg/kg fresh weight)				
Garden	Mean	SD	Min	Max	*N*	Mean	SD	Min	Max	*N*	Mean	SD	Min	Max	*N*	Mean	SD	Min	Max	*N*
1	39.8	10.0	32.8	54.7	4	0.9	0.2	0.6	1.2	4	0.23	0.03	0.20	0.27	3	0.09	0.05	0.06	0.15	3
2	66.4	22.9	31.1	102.4	6	2.0	0.7	0.7	2.6	6	0.00	0.01	0.00	0.01	3	0.03	0.02	0.01	0.06	3
3	123.2	23.9	94.9	158.6	9	1.4	0.2	1.2	1.8	9	0.09	0.13	0.00	0.28	4	0.08	0.01	0.06	0.09	4
4	44.2	14.6	28.8	62.9	4	1.0	0.2	0.7	1.1	4	0.06	0.05	0.02	0.09	2	0.12	0.08	0.06	0.18	2
5	127.9	79.1	49.7	238.2	5	4.4	2.7	2.1	8.9	5	0.21	0.01	0.20	0.21	3	0.03	0.01	0.03	0.04	3

None of the leafy green samples collected from the gardens contained Pb or Cd above EU maximum limits for leafy greens (0.3 mg Pb/kg fresh wt; 0.2 mg Cd/kg fresh wt.) (Figure 3, Appendix 1). Cd content of store-bought, conventionally-grown leafy greens ranged from 0.3 to 0.4 mg/kg fresh weight, which is above EU limits. Pb content of store-bought, conventionally-grown leafy greens was below the detection limit.

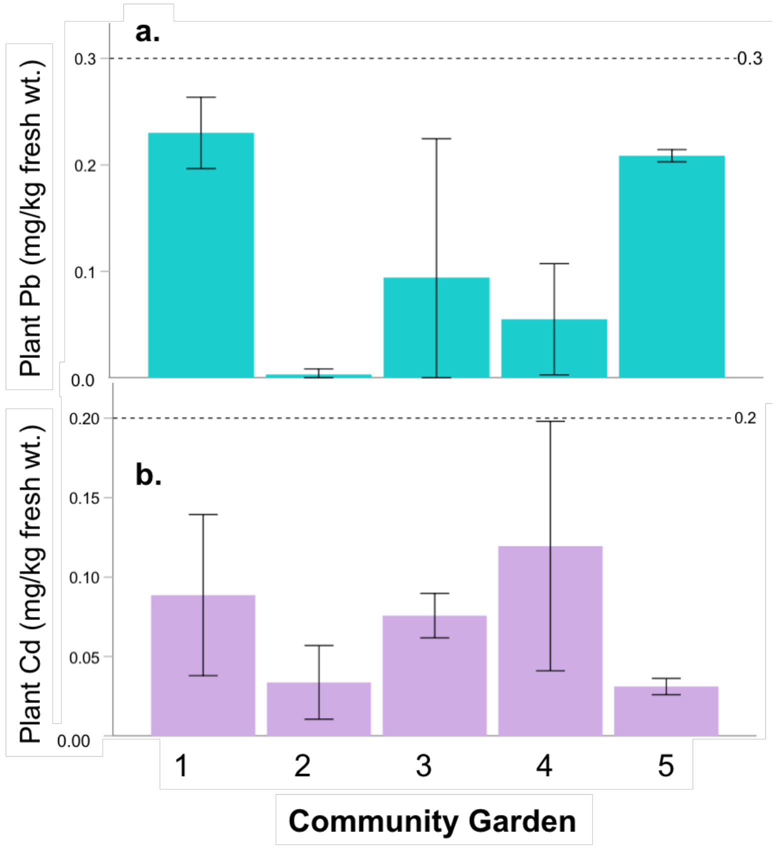


Figure 3. (a) Leafy green Pb concentration (mg/kg fresh weight) and (b) Cd concentration (mg/kg fresh weight) from community gardens in metro Phoenix. Error bars are +/- 1 standard deviation. Reference lines are shown for the EU maximum limit for leafy green vegetables for Pb (0.3 mg/kg fresh weight) and Cd (0.2 mg/kg fresh weight).

In addition to testing for heavy metal content, we explored the relationship between metal content of leafy greens and soil properties, including pH, soil organic matter, and soil texture. Soil properties varied across community gardens (Table 5) but all were relatively sandy (average 44-69% sand), neutral to moderately alkaline (average pH 7.4-8.4), and moderately organic (average 16-20% organic matter).

Table 5. Soil properties in community gardens across metro Phoenix. SOM = Soil organic matter; SD = standard deviation; *N* = number of samples analyzed.

Garden	Soil variable	Mean	SD	Min	Max	*N*
1	SOM (%)	16.3	3.1	11.8	18.6	4
	pH	8.4	0.3	8.0	8.7	4
	Sand (%)	65.0	1.0	63.0	66.0	4
	Silt (%)	32.0	1.0	30.0	33.0	4
	Clay (%)	4.0	0.0	4.0	4.0	4
2	SOM (%)	20.0	11.2	5.3	32.8	6
	pH	7.4	0.2	7.1	7.7	6
	Sand (%)	69.0	13.0	53.0	83.0	6
	Silt (%)	25.0	9.0	13.0	39.0	6
	Clay (%)	6.0	5.0	1.0	14.0	6
3	SOM (%)	16.6	6.5	9.7	29.1	9
	pH	8.0	0.3	7.4	8.4	9
	Sand (%)	44.0	10.0	31.0	58.0	9
	Silt (%)	41.0	6.0	30.0	48.0	9
	Clay (%)	15.0	5.0	9.0	24.0	9
4	SOM (%)	16.6	12.1	7.7	33.8	4
	pH	8.3	0.2	8.0	8.5	4
	Sand (%)	50.0	16.0	29.0	67.0	4
	Silt (%)	38.0	10.0	27.0	50.0	4
	Clay (%)	12.0	7.0	6.0	21.0	4
5	SOM (%)	18.1	8.7	10.8	33.3	5
	pH	8.0	0.4	7.4	8.4	5
	Sand (%)	67.0	2.0	64.0	69.0	5
	Silt (%)	29.0	3.0	24.0	33.0	5
	Clay (%)	5.0	1.0	4.0	6.0	5

Plant Pb content was not significantly related to soil Pb or Cd, or any other soil properties. Plant Cd concentration was significantly and negatively correlated to % sand ($r = 0.52$; $p < 0.05$). Soil Pb was significantly and positively related to soil Cd ($r = 0.5$, $p = 0.01$), but it was not related to plant Pb or plant Cd content, nor soil properties. Soil Cd content was not significantly related to plant Cd, nor other soil properties except soil Pb content.

We tested for differences in soil metal content between beds that were located in the ground compared to raised beds (Figure 4; garden 3 only). Pb and Cd concentration in the soil did not differ significantly between in-ground and raised beds (Mann Whitney U test, $p > 0.1$).

We also tested for differences in soil metal content between surface samples (0-15 cm) and deeper samples (15-30 cm) in raised beds (Figure 5; gardens 2, 3, 4, and 5 used in statistical analyses). Pb and Cd concentration in soil did not differ significantly between soil depths ($p > 0.4$ for both Pb and Cd).

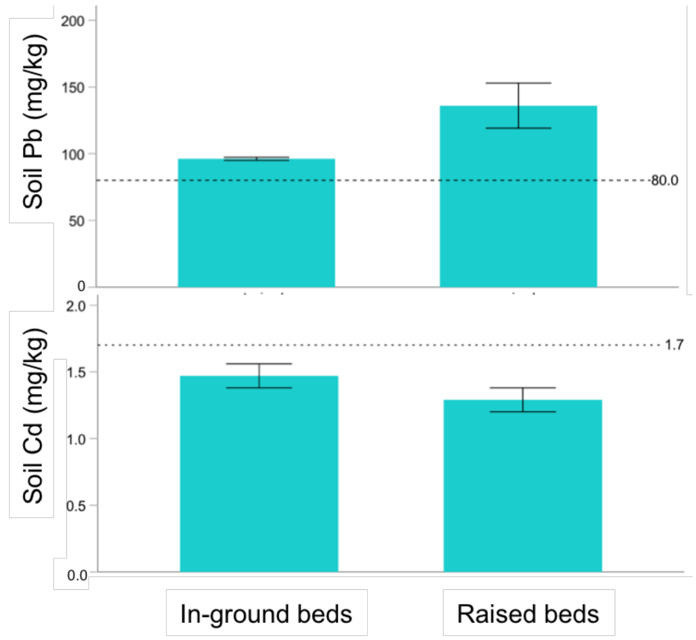


Figure 4. Soil Pb and Cd content in raised and in-ground planting beds at garden 3 (0-15 cm soil depth; N=3 samples in each bed type). Error bars are +/- 1 standard deviation. Dotted lines are California advised limits for soil Pb and Cd.

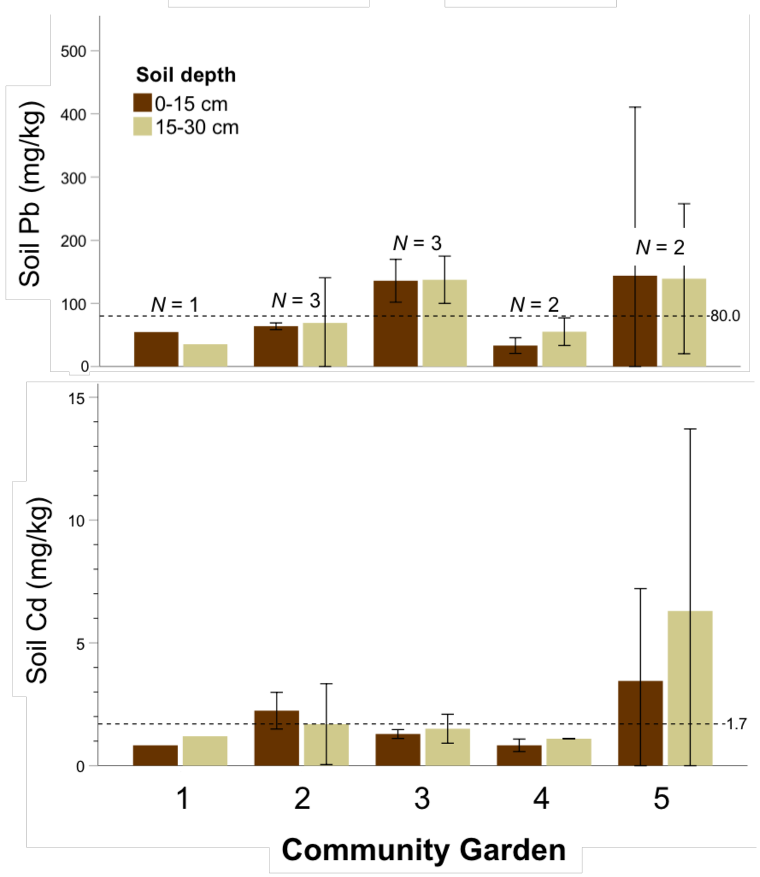


Figure 5. Soil Pb and Cd concentration in surface soil (0-15 cm depth) and subsurface soil (15-30 cm) of raised beds in each garden. Shown is the number of samples analyzed (*N*) for each depth in each garden and the California reference limit for soil Pb and Cd. Error bars are +/- 1 standard deviation.

Finally, we compared patterns of soil Pb content from our gardens to a previous city-wide survey of soil metals (Figure 6; Zhuo 2010). Interpolated neighborhood soil Pb was not significantly related to garden soil Pb, although the trends are intriguing despite the low sample size.

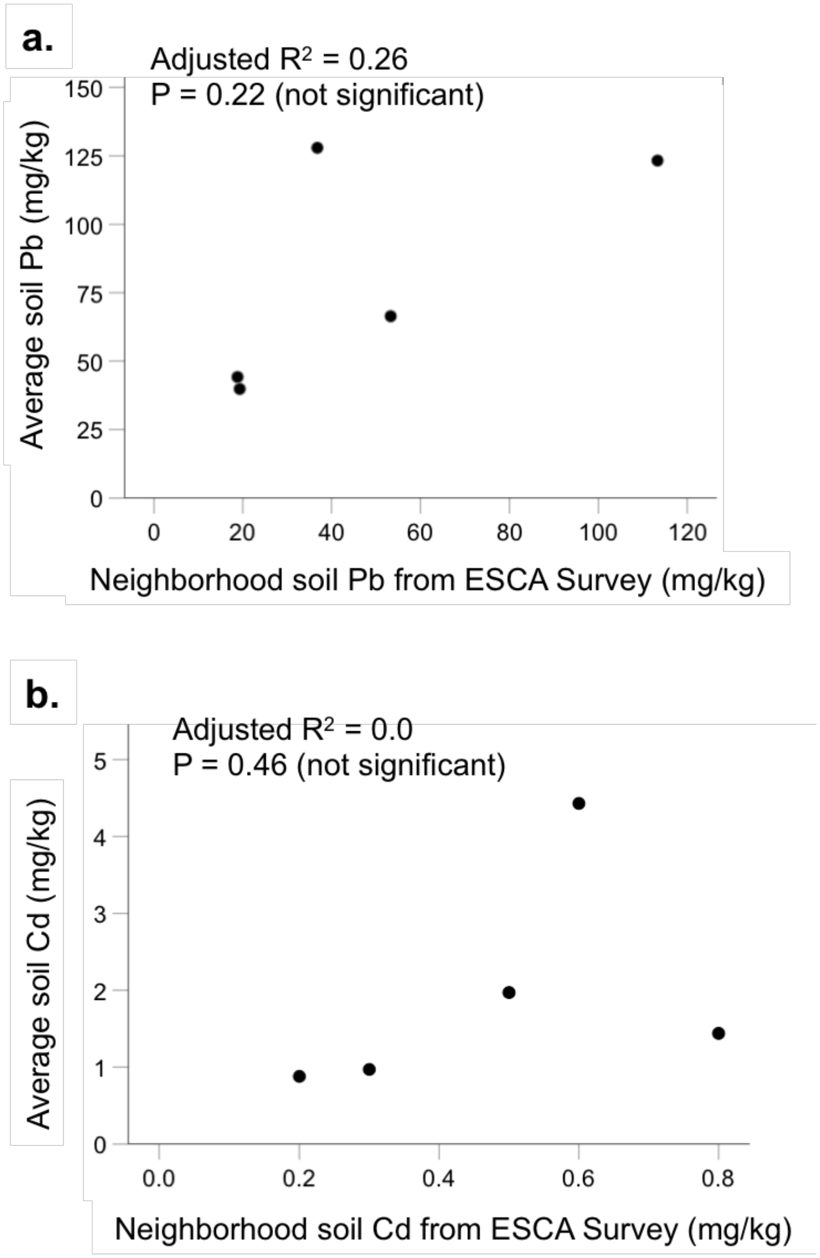


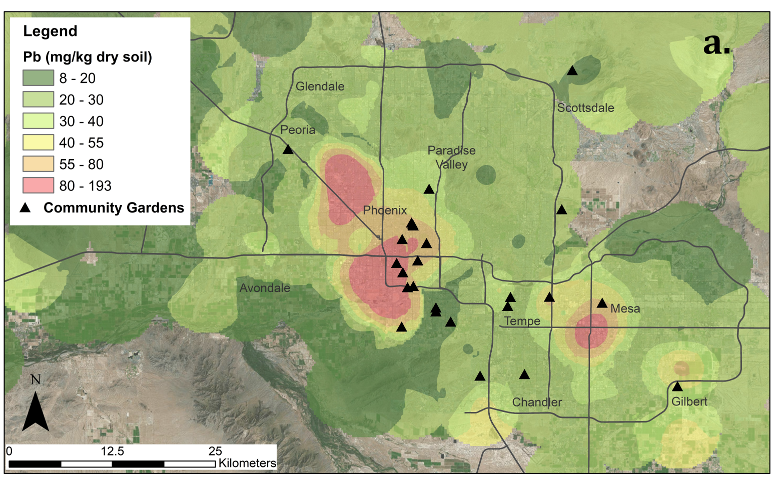
Figure 6. Average a) soil Pb and b) soil Cd content in each of the 5 gardens (black circles) in relation to interpolated neighborhood surface soil Pb and Cd from samples (0-15 cm depth) that were collected and analyzed as a part of the Ecological Survey of Central Arizona (ESCA; from Zhuo and Shock 2010).

5. Discussion

Among the five gardens evaluated for heavy metal content in this study, three were above California health screening limits for soil but below current US EPA limits. High soil Pb and Cd levels at these particular locations could be due to their previous land uses and proximity to local and regional sources of heavy metals. Two of these three gardens are near the historic city center and within close proximity to a factory and railroads. Furthermore, the land at these sites was historically used for agriculture and Pb paint was once used on at least one of these properties, as is common for older neighborhoods.

Soil Pb and Cd in raised beds may also be related to the metal content of imported soil, or from old wood (if there is Pb paint) or tires (contain Cd) that were used to create the bed. This possibility is particularly relevant in one of our study gardens, which uses repurposed tires as raised beds. Worn tires can release Pb and Cd into soil (Adachi and Tainosho 2004).

Although not statistically significant, we observed a potentially interesting relationship between garden location and city-wide soil metal content. Data from a city-wide survey (Zhuo 2010, Zhuo et al. 2012) shows that soil Pb and Cd concentrations are related to former urban and industrial activities in downtown Phoenix and Mesa (Figure 7; Zhuo et al. 2012). Future research should explore this hypothesis across a wider range of community gardens across the metropolitan area. Understanding the relationship between garden metal content and metal patterns across the city could inform the establishment of future community gardens, or remediation of soil prior to food production.



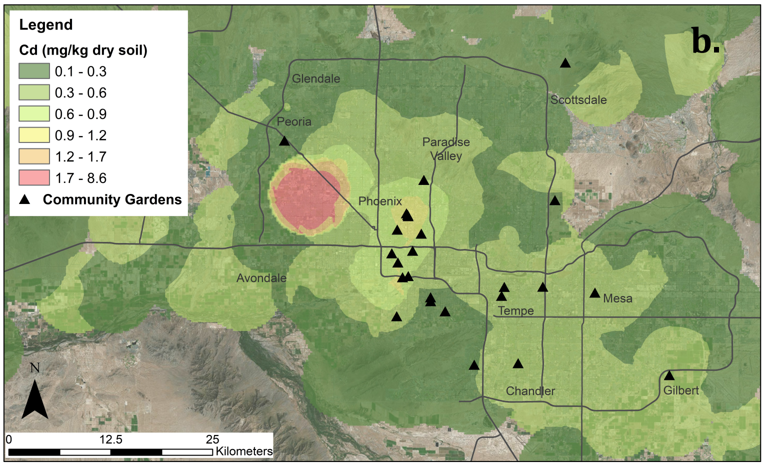


Figure 7. Current location of community gardens (triangles) relative to surface Soil a) Pb concentration (mg/kg, 0-15 cm), and b) Cd concentration (mg/kg, 0-15 cm), interpolated from the 200-point ESCA Survey (data from Zhuo, 2010; and Zhuo and Shock, 2012). Red color indicates soils are above the California health screening advised limit for Pb (80 mg/kg) and Cd (1.7 mg/kg) in residential soil. Five of these gardens were sampled in this study. Higher concentrations of soil Pb occur in the central and southeastern parts of the Phoenix metro area due to former use of lead gasoline and lead-based paint.

6. Conclusions and recommendations

We found no instances of soil or plant Pb or Cd content above federal soil limits in any of the five community gardens in this study. However, soil Pb and Cd content in some gardens exceeded California health screening limits. Higher soil metal content in some gardens may be related in part to the geographical location of the community garden, Pb paint on older homes adjacent to gardens, or metal in imported soil and materials used to create raised beds.

Metal content of community garden soils were not significantly related to city-wide patterns of soil heavy metals, but further study is needed to verify this finding. Although soil and leafy greens from our study gardens contained low to moderate Pb and Cd content, communities would benefit from more thorough testing to explore the source of heavy metals in order to remediate in-ground or imported soils. Local municipalities, state governments, or non-profits could provide grants to fund soil testing for urban gardens. Ultimately, creation and enforcement of local, state or federal soil health standards for community gardens would educate citizens and consumers, and help to improve food safety.

In order to minimize crop uptake of contaminants, agriculturalists recommend a variety of remediation techniques to limit the exposure of humans to heavy metals (Angima and Sullivan 2008, Sowerwine et al. 2018). Soil management actions that increase soil pH (for example, through the addition of lime) make metals less available to plants and less likely to be incorporated in plant tissues (Chuan et al. 1996, NRCS 2000). In addition, the application of soil organic matter in the form of manure or compost can immobilize metals, provided that the imported soil itself is low in metal content (Prasad 2002). Filling raised beds with clean, imported soil is a manageable alternative to in-ground planting (Clark et al. 2008). Additionally, deep tillage is used to minimize plant uptake of metals by diluting the topsoil where most annual plant roots grow (Angima and Sullivan 2008). However, soil testing should occur first to ensure that deeper soil is not contaminated. Ultimately, remediation techniques can limit the exposure of humans to heavy metals by reducing metal solubility and availability (Angima and Sullivan 2008).

For more information on soil testing, remediation, and how to avoid heavy metal contamination, we recommend visiting these resources:

1) Soil and Water Testing Guidelines for Home and Community Gardens: http://publichealth.lacounty.gov/eh/docs/AB1990_SoilWaterTestingGuidelines.pdf
2) Brownfields and Urban Agriculture: Interim Guidelines for Safe Gardening Practices: https://www.epa.gov/sites/production/files/2015-09/documents/bf_urban_ag.pdf

Appendix 1. Soil and plant data from the five community gardens used in this study.

Garden #	Bed Type	Sample #	Soil depth (cm)	Organic Matter %	pH	% Clay	% Silt	% Sand	Soil Pb (mg/kg)	Soil Cd (mg/kg)	Plant Pb (mg/kg fresh weight)	Plant Cd (mg/kg fresh weight)
1	not raised	1	0-15	18.1	8.3	4	33	63	36.52	0.83	0.202	0.064
1	not raised	2	0-15	18.64	8.01	4	30	66	32.84	0.64	0.267	0.055
1	raised	3	0-15	16.65	8.64	4	32	64	54.65	0.83		
1	raised	4	15-30	11.78	8.65	4	31	65	35.33	1.2	0.221	0.147
2	raised	1	0-15	18.45	7.5	4	13	83	65.96	1.84	0.009	0.009
2	raised	2	0-15	32.76	7.2	1	20	78	64.77	2.3	0	0.037
2	raised	3	0-15	27.69	7.13	2	21	76	60.90	2.58	0	0.055
2	raised	4	15-30	5.34	7.74	11	23	66	102.40	2.21		
2	raised	5	15-30	27.12	7.44	6	39	55	73.51	2.12		
2	raised	6	15-30	8.46	7.29	14	33	53	31.10	0.74		
3	not raised	1	0-15	15.13	7.98	24	45	31	94.94	1.47	0.101	0.092
3	not raised	2	0-15	17.27	7.86	21	44	35	96.42	1.56		
3	not raised	3	0-15	11.09	8.16	19	45	36	97.15	1.38		
3	raised	4	0-15	23.33	8.07	9	36	55	144.16	1.38	0	0.064
3	raised	5	0-15	29.09	7.35	12	30	58	116.47	1.2	0.276	0.083
3	raised	6	0-15	14.78	8.12	9	38	54	147.38	1.29	0	0.064
3	raised	7	15-30	9.69	8.22	11	39	50	122.73	1.29		
3	raised	8	15-30	19.38	8.11	14	44	42	158.61	1.38		
3	raised	9	15-30	9.76	8.38	16	48	36	131.28	1.84		
4	raised	1	0-15	33.8	8.22	6	27	67	28.80	0.74	0.018	0.064
4	raised	2	0-15	15.89	8.36	11	34	54	37.54	0.92	0.092	0.175
4	raised	3	15-30	7.72	7.98	9	42	49	62.93	1.1		
4	raised	4	15-30	8.8	8.51	21	50	29	47.47	1.1		
5	not raised	1	0-15	15.12	7.36	6	24	69	73.60	2.67	0.202	0.037
5	raised	2	0-15	15.83	8.13	4	30	66	49.68	4.78	0.212	0.028
5	raised	3	0-15	33.28	8.4	4	28	69	238.19	2.12	0.212	0.028
5	raised	4	15-30	10.79	8.06	6	28	66	181.16	8.92		
5	raised	5	15-30	15.43	7.85	4	33	64	97.06	3.68		

Literature cited

Adachi, K., and Y. Tainosho. 2004. Characterization of heavy metal particles embedded in tire dust. Environment International **30**:1009-1017.

AZDEQ. 1991. Evaluation of background metals concentrations in Arizona soils. Arizona Department of Environmental Quality. http://legacy.azdeq.gov/function/forms/list.html.

Angima, S. D., and D. M. Sullivan. 2008. Evaluating and Reducing Lead Hazard in Gardens and Landscapes. Oregon State University Extension Service.

ATSDR. 2007. Toxicological Profile for Lead. Agency for Toxic Substances and Disease Registry (ATSDR), U.S. Department of Health and Human Services, Public Health Service, Atlanta, GA.

ATSDR. 2012. Toxicological Profile for Cadmium. Agency for Toxic Substances and Disease Registry (ATSDR), U.S. Department of Health and Human Services, Public Health Service, Atlanta, GA.

Bouyoucos, G. J. 1962. Hydrometer Method Improved for Making Particle Size Analysis of Soils. Agronomy Journal **54**:464-465.

CalEPA OEHHA. 2009. Soil and soil gas screening numbers (mg/kg soil) for nonvolatile chemicals based on total exposure to contaminated soil: inhalation, ingestion, and dermal absorption. California Office of Environmental Health Hazard Assessment (OEHHA) Risk Assessment,. https://oehha.ca.gov/chhsltable.

Cameron, R. W. F., T. Blanusa, J. E. Taylor, A. Salisbury, A. J. Halstead, B. Henricot, and K. Thompson. 2012. The Domestic Garden – Its Contribution to Urban Green Infrastructure. Urban Forestry and Urban Gardening **11**:129-137.

Carlon, C., M. D'Alessandro, and F. Swartjes. 2007. Derivation methods of soil screening values in Europe: a review of national procedures towards harmonisation. Page 90 EUR. Scientific and Technical Research Series. Joint Research Center, Office for Official Publications of the European Communities. https://era.org.mt/en/Documents/soil screening values_ EU rep.PDF.

CDPH. 2014. Growing and Eating Fruits and Vegetables Safely. Connecticut Department of Public Health, Environmental & Occupational Health Assessment Program, Hartford, CT.

Chaney, R. L., S. B. Sterrett, and H. W. Mielke. 1984. The potential for heavy metal exposure from urban gardens and soils. Univ. Dist. Columbia Extension Service, Washington, DC.

Chang, C. Y., H. Y. Yu, J. J. Chen, F. B. Li, H. H. Zhang, and C. P. Liu. 2013. Accumulation of Heavy Metal in Leaf Vegetables From Agricultural Soils and Associated Potential Health Risks in the Pearl River Delta, South China. Environmental Monitoring and Assessment **186**:1547-1560.

Chuan, M. C., D. Y. Shu, and J. C. Liu. 1996. Solubility of Heavy Metals in a Contaminated Soil: effects of redox potential and pH. Water, Air, and Soil Pollution **90**:543-556.

Clark, H. F., D. M. Hausladen, and D. J. Brabancer. 2008. Urban Gardens: Lead Exposure, Recontamination Mechanisms, and Implications for Remediation Design. Environmental Research **107**:312-319.
Colbourn, P., and I. Thornton. 2006. Lead Pollution in Agricultural Soils. Journal of Soil Science **29**:513-526.
CT DPH. 2014. Fact Sheet: What you need to know about growing and eating fruits and vegetables safely. Connecticut Department of Public Health. http://www.portal.ct.gov/-/media/Departments-and-Agencies/DPH/dph/environmental_health/eoha/pdf/SafeGardeningfactsheet2014revpdf.pdf?la=en.
Dunnett, N., and M. Qasim. 2000. Perceived Benefits to Human Well-Being of Urban Gardens. HortTechnology **10**:40-45.
EC. 2006. Commission Regulation (EC), Setting Maximum Levels for Certain Contaminants in Foodstuffs. Official Journal of the European Union. https://eur-lex.europa.eu/legal-content/EN/ALL/?uri=CELEX:32006R1881.
EPA. 1996. Microwave Assisted Acid Digestion of Siliceous and Organically Based Matrices (Method 3052). Environmental Protection Agency Washington, D.C.
EPA. 2011a. Intake of Fruits and Vegetables. Environmental Protection Agency, Washington, D.C.
EPA. 2011b. Reusing Potentially Contaminated Landscapes: Growing Gardens in Urban Soil. Environmental Protection Agency, Washington, D.C.
ERS. 2015. Food Access Research Atlas. Economic Research Service, U.S. Department of Agriculture (USDA). https://www.ers.usda.gov/data-products/food-access-research-atlas/.
FDA. 2017. Questions and Answers on Lead in Foods. https://www.fda.gov/Food/FoodborneIllnessContaminants/Metals/ucm557424.htm.
Finster, M. E., K. A. Gray, and H. J. Binns. 2004. Lead Levels of Edibles Grown in Contaminated Residential Soils: A Field Survey. Science of The Total Environment **320**:245-257.
Fitzpatrick, J. 2013. Downtown's 'food desert' classification creates difficulties for residents shopping for groceries. Downtown Devil, Tempe, AZ.
Gee, G. W., and J. W. Bauder. 1986. Methods of Soil Analysis, Part I, 2nd ed., American Society of Agronomy/Soil Science Society of America, Madison, WI.
Ghose, R., and M. Pettygrove. 2014. Urban Community Gardens as Spaces of Citizenship. Antipode **46**:1092-1112.
Goyer, R. A. 1995. Nutrition and Metal Toxicity. American Journal of Clinical Nutrition **61**:646S-650S.
Gublo, F. 2015. The high cost of soil testing for urban agriculture makes financial sustainability questionable. Michigan State University Extension. http://msue.anr.msu.edu/news/the_high_cost_of_soil_testing_for_urban_agriculture_makes_financial_sustain.

Hettiarachchi, G. M., and G. M. Pierzynski. 2004. Soil Lead Bioavailability and in situ Remediation of Lead-contaminated Soils: a Review. Environmental Progress **23**:78-93.
HHS. 2014. Federal Poverty Guidelines, 79 FR 3593. Federal Register, Department of Health and Human Services.
Hibben, C. R., S. S. Hagar, and C. P. Mazza. 1984. Comparison of Cadmium and Lead Content of Vegetable Crops Grown in Urban and Suburban Gardens Environmental Pollution Series B. Chemical and Physical **7**:71-80.
Holmer, R. J. 2011. Vegetable Gardens Benefit the Urban Poor in the Philippines. Appropriate Technology **38.2**:49-51.
Huisingh, D. 1974. Heavy Metals: Implications for Agriculture. Annual Review of Phytopathology **12**:375-388.
Islam, E. U., X.-E. Yang, Z.-L. He, and Q. Mahmood. 2007. Assessing Potential Dietary Toxicity of Heavy Metals in Selected Vegetables and Food Crops. Journal of Zhejiang University SCIENCE B **8**:1-13.
Kim, H., K. Kim, G. Lim, J. Kim, and K. H. Kim. 2015. Influence of airborne dust on the metal concentrations in crop plants cultivated in a rooftop garden in Seoul. Soil Science and Plant Nutrition **61**:88-97.
Lanphear, B. P., T. D. Matte, J. Rogers, R. P. Clickner, B. Dietz, R. L. Bornschein, P. Succop, K. R. Mahaffey, S. Dixon, W. Galke, M. Rabinowitz, M. Farfel, C. Rohde, J. Schwartz, P. Ashley, and D. E. Jacobs. 1998. The Contribution of Lead-Contaminated House Dust and Residential Soil to Children's Blood Lead Levels: a Pooled Analysis of 12 Epidemiologic Studies. Environmental Research **79**:51-68.
Lasch, A. 2012. Food Deserts in America.
Lazrus, A. L., E. Lorange, and J. J. P. Lodge. 1970. Lead and Other Metal Ions in United States Precipitation. Environmental Science & Technology **4**:55-58.
McLean, J. E., and B. E. Bledsoe. 1992. Behavior of Metals in Soils. EPA, Washington, D.C.
Mushak, P. 2011. Lead and Public Health: Science, Risk and Regulation of Trace Metals and other Contaminants in the Environment. Elsevier.
Naveedullah, M. Z. Hashmi, C. Yu, H. Shen, D. Duan, C. Shen, L. Lou, and Y. Chen. 2013. Risk Assessment of Heavy Metals Pollution in Agricultural Soils of Siling Reservoir Watershed in Zhejiang Province, China. BioMed Research International **590306**.
NRCS. 2000. Heavy metal soil contamination. US Department of Agriculture, Natural Resources Conservation Service, Auburn, AL.
NY DEC. 2006. 6 NYCRR PART 375 Environmental Remediation Programs, New York State Department of Environmental Conservation. https://www.dec.ny.gov/docs/remediation_hudson_pdf/part375.pdf.
OSHA. 2014. Safety and Health Topics: Lead.*in* Occupational Safety & Health Administration, editor. U.S. Department of Labor, Washington, D.C.
Prasad, M. N. V. 2002. Phytoremediation of Metal-Polluted Ecosystems: Hype for Commercialization. Russian Journal of Plant Physiology **50**:686-700.

Pulido, L. 2000. Rethinking Environmental Racism: White Privilege and Urban Development in Southern California. Annals of the Association of American Geographers **90**:12-40.
Salvagio Manta, D., M. Angelone, A. Bellanca, R. Neri, and M. Sprovieri. 2002. Heavy Metals in Urban Soils: a Case Study from the City of Palermo (Sicily), Italy Science of The Total Environment **300**:229-243.
Samnegard, U., A. S. Persson, and H. G. Smith. 2011. Gardens Benefit Bees and Enhance Pollination in Intensively Managed Farmland. Biological Conservation **144**:2062-2606.
Satarug, S., M. R. Haswell-Elkins, and M. R. Moore. 2000. Safe Levels of Cadmium Intake to Prevent Renal Toxicity. British Journal of Nutrition **84**:791-802.
Satarug, S., and M. R. Moore. 2004. Adverse Health Effects of Chronic Exposure to Low-Level Cadmium in Foodstuffs and Cigarette Smoke. Environmental Health Perspectives **112**:1099-1103.
Schulte, E. E., and B. G. Hopkins. 1996. Soil organic matter: analysis and interpretation. Soil Science Society of America, Madison.
Shacklette, H. T. I., and J. G. Boerngen. 1984. Element concentrations in soils and other surficial materials of the conterminous United States: an account of the concentrations of 50 chemical elements in samples of soils and other regoliths. United States Government Printing Office, Washington, D.C.
Singh, B., R. Narwal, A. Jeng, and A. Almas. 1995. Crop Uptake and Extractability of Cadmium in Soils Natural High in Metals at Different pH Levels. Communications in Soil Science and Plant Analysis **26**:2123-2142.
Sowerwine, J., C. Oatfield, R. Bennaton, A. Pires, R. Surls, V. Borel, and A. Biscaro. 2018. California Urban Agriculture Food Safety Guide: Laws and Standard Operating Procedures for Farming Safely in the City. UC Berkeley, UC Cooperative Extension, and Sustainable Economies Law Center.
Spittler, T. M., and W. A. Feder. 1979. A Study of Soil Contamination and Plant Lead Uptake in Boston Urban Gardens. Communications in Soil Science and Plant Analysis **10**:1195-1210.
Stilwell, D. E., T. M. Rathier, C. L. Musante, and J. F. Ranciato. 2008. Lead and other heavy metals in community garden soils in Connecticut. The Agricultural Experiment Station, New Haven, CT.
Toth, G., T. Hermann, M. R. Da Silva, and L. Montanarella. 2016. Heavy metals in agricultural soils of the European Union with implications for food safety. Environment International **88**:299-309.
US EPA. 1993. Clean Water Act, Biosolids Laws and Regulations, 58 FR 9248, 40 CFR Part 503. https://www.epa.gov/biosolids/biosolids-laws-and-regulations.
US EPA. 2001. Lead; Identification of Dangerous Levels of Lead; Final Rule; 40 CFR Part 745. https://www.gpo.gov/fdsys/pkg/FR-2001-01-05/pdf/01-84.pdf.

US EPA. 2014. Technical review workgroup (TRW) recommendations regarding gardening and reducing exposure to lead-contaminated soils, OSWER 9200.2-142. Office of Solid Waste and Emergency Response, US EPA.
US EPA. 2018. Regional Screening Levels for Chemical Contaminants at Superfund Sites.
US EPA IRIS. 1985. Cadmium. Integrated Risk Information System. Environmental Protection Agency, Washington, D.C. https://cfpub.epa.gov/ncea/iris/iris_documents/documents/subst/0141_summary.pdf.
Ver Ploeg, M., D. Nulph, and R. Williams. 2011. Mapping Food Deserts in the United States. Amber Waves. US Department of Agriculture, Economic Research Service, https://www.ers.usda.gov/amber-waves/2011/december/data-feature-mapping-food-deserts-in-the-us/.
Zhuo, X. 2010. Distributions of Toxic Elements in Urban Desert Soils. Arizona State University, Tempe, AZ.
Zhuo, X., C. G. Boone, and E. L. Shock. 2012. Soil lead distribution and environmental justice in the Phoenix metropolitan region. Environmental Justice **5**:206-213.
Zhuo, X., and E. L. Shock. 2010. Ecological Survey of Central Arizona: Soil trace elements.*in* Central Arizona–Phoenix Long Term Ecological Research Project, editor., Arizona State University.