SOURCES AND PATHWAYS OF LEAD CONTAMINATION IN URBAN COMMUNITY
GARDENS IN TOLEDO, OHIO

Brett Merkley

A Thesis

Submitted to the Graduate College of Bowling Green
State University in partial fulfillment of
the requirements for the degree of

MASTER OF SCIENCE

May 2019

Committee:

John Farver, Advisor

Peter Gorsevski

Yuning Fu

ABSTRACT

John Farver, Advisor

Blood lead levels (BLLs) in children of the Toledo, OH area have been elevated for decades, and numerous studies have linked the issue to soil contamination by lead (Pb) paint and leaded gasoline. Young children below the age of 4 years have proven the most susceptible to Pb poisoning due to their high Pb absorption rates and direct ingestion of Pb contaminated sources resulting from instinctive hand-to-mouth behaviors. This problem is significant because high BLLs can result in many pathological and developmental problems including irreversible fetal brain damage, brain damage to the developing prefrontal cortex, behavioral problems, violence, learning disabilities, and more.

The objectives of this study were to determine the primary factors leading to Pb and other heavy metals contamination in community gardens in Toledo, OH. A total of 399 samples were collected across 27 community gardens, of which 218 (including soil profiles of 14 gardens) were analyzed for heavy metals using an ICP-OES. Soil profiles were collected down to 40 cm depth (or maximum achievable depth) and subsampled at 5 cm intervals to determine Pb distribution with depth.

Using the historical Sanborn Fire Insurance maps combined with the distribution of Pb within gardens across properties, it was found that drip zones, a 1-meter area of soil immediately surrounding structures containing Pb paint, is the main predictor for contamination above the 100 mg/kg action level threshold set by the USEPA (2014). The maps also proved critical for determining the locations of drip zones and other aspects of land use history. Other significant

factors found to influence soil Pb concentration include proximity to high traffic roads, tilling practices, thickness of garden soil, and garden age. Of lesser importance but still significant was the source of garden soil, presence and quality of liners, and wind transportation of Pb particles.

Given the rising popularity of urban community gardens it is more important than ever to understand the sustainability of current gardening practices for minimizing exposure to Pb.

Factors effecting garden soil Pb levels in Toledo, OH are universal to many urban areas, consequently these findings are applicable to other cities as well.

ACKNOWLEDGMENTS

Special thanks to the Geological Society of America as well as the Richard D. Hoare award through Bowling Green State University for helping fund this project. Without their financial support this study would not have been possible. Gratitude also goes out to Toledo Grows which provided outreach and the community gardeners who provided access to their gardens. Additional thanks to Blane Houck and Priyanka More for helping with some of the fieldwork. And finally, thanks to Dr. John Farver for providing the idea for this project and advising and guiding me through much of it. His help has been critical and is greatly appreciated.

TABLE OF CONTENTS

	Page
INTRODUCTION	1
Factors Impacting Heavy Metals in Garden Soil.....	5
Bioavailability.....	10
METHOD AND MATERIALS	11
Study Area and Past Land Use.....	11
Determining Gardening Practices	12
Field Sampling.....	13
Sample Preparation, Analysis, and Quality Control	15
Predictive Blood Lead Level Modeling.....	16
RESULTS	18
DISCUSSION.....	21
Distribution of Lead.....	21
Site 1 (Figures 3-5)	22
Sites 2-3 (Figures 6-11)	23
Site 4 (Figures 12-14)	22
Site 5 (Figures 15-16)	23
Comparison with Other Soil Lead Studies.....	26
Other Heavy Metals	26
Health Risk Assessment.....	27
Ranking Impact Factors of Garden Soil Lead.....	30
Soil Remediation Strategies.....	34
Titanium as an Indicator of Lead Paint.....	36

SUMMARY.....	38
REFERENCES	40
APPENDIX A. FIGURES	51
APPENDIX B. TABLES	84
APPENDIX C. QUESTIONS POSED TO GARDNERS.....	87
APPENDIX D. TOTAL ORGANICS ARE REPRESENTED BY WEIGHT LOSS.....	88
APPENDIX E. SAMPLE DESCRIPTIONS AND DATA.....	93
APPENDIX F. SHOWING POTENTIAL SOURCES.....	101

LIST OF FIGURES

Figure	Page
1 Lucas County Lead Poisoning Map (from Ohio 2016 State Health Assessment) Confirmed elevated blood lead levels (> 5 ug/dL) per 1,000 children under age 6, by census tract (2010-2014).....	51
2 Revised from Stewart et al., (2014) showing risk of elevated BLLs overlain by predicted BLL values for Toledo, OH. Their study showed that age of housing modeled a best fit for predicting BLL risk. Stars represent garden sample sites where profiles were collected in this study.....	52
3 Profile Site 1. A satellite image of a property containing gardens with an overlain Sanborn Fire Insurance map showing the outline of a house formerly located at the property. The red rectangle represents a drip zone where gardens are located. Numbers 1 and 2 represent profile samples collected in raised beds, with 3 and 4 representing samples from an in-ground bed. Stars #1-2 represent raised bed samples while Star #3 represents a pathway sample. Results and depths for background samples are given in the white box on the figure. A photo of the garden is shown in Figure 4. Results are plotted in Figure 5. Additional details on these samples can be found in the P-2-2 section of Appendix 3	53
4 Profile Site 1. A photograph of the garden area from Figure 3 with sample locations displayed (assistant for scale towards the left-center). Results for the profiles are plotted in Figure 5.....	54
5 Profile Site 1. Lead profiles of the gardens featured in Figures 4 and 5. The first vertical dashed line represents the 100 mg/kg EPA threshold for gardens and the	

	second the 400 mg/kg EPA threshold for areas children can play. The horizontal dashed line marks the boundary between raised bed soil and local soil. Three aliquots were processed at 30 cm depth for Raised Bed 2 which returned an average of 1655 ± 55 mg/kg Pb. Note that Pb values are below both EPA thresholds for the raised beds, but both are exceeded in the local soil. Additional details on these samples can be found in the P-2-2 section of Appendix 3	55
6	Profile Site 2. A satellite image of a garden location with an overlain Sanborn Fire Insurance map showing the outlines of several houses formerly located here. One profile was analyzed for a 5 year old garden and three profiles for 14 year old gardens. Additional surface and depth samples were processed for the location indicated by the star (1 at surface, 1 at 32 cm depth). Images of the raised beds are given in Figure 7, with Pb results for the profiles plotted in Figure 8. Additional details on these samples can be found in the P-2-7 section of Appendix 3	56
7	Profile Site 2. Photographs of the gardens with the auger for scale also indicating where the samples were collected. Results for the profiles are plotted in Figure 8...	57
8	Profile Site 2. Lead profiles of the gardens featured in Figures 6 and 7. The vertical dashed line represents the 100 mg/kg EPA threshold for gardens. The horizontal dashed line marks the boundary between raised bed soil and local soil. Note that Pb values are close to or exceed the EPA threshold for gardening within the raised beds and clearly exceeds the threshold upon entry into the local soil. Additional details on these samples can be found in the P-2-7 section of Appendix 3.....	58

- 9 Profile Site 3. A satellite image with an overlain Sanborn Fire Insurance map showing the outline of a house formerly located at the property. Stars represent locations where non-profile samples were collected. Star #1 represents a sample analyzed for the back area behind the gardens. Star #2 is a depth sample collected on the other side of the same garden where profile samples were collected. Images for sampled gardens are shown in Figure 10 and results are plotted in Figure 11. Additional details on these samples can be found in the P-2-3 section of Appendix 3..... 59
- 10 Profile Site 3. A photograph of the gardens mapped in Figure 9. Augers for scale also representing where profiles were collected. Results for the profiles are plotted in Figure 11 60
- 11 Profile Site 3. Lead profiles of the gardens featured in Figures 9 and 10. The vertical dashed line represents the 100 mg/kg EPA threshold for gardens. The horizontal dashed line marks the boundary between raised bed soil and local soil. Initially, measurements of surface samples were elevated beyond 100 mg/kg. However, new surface aliquots of raised bed P2-3-1 ranged 40-47 mg/kg, with an aliquot of raised bed P2-3-3-15 at 20 mg/kg (resulting in a corrected estimation of P2-3-3-10 of 29 mg/kg). Additional details on these samples can be found in the P-2-3 section of Appendix 3 61
- 12 Profile Site 4. A satellite image combined with a Sanborn Fire Insurance map showing former locations of storefronts along a well-traveled road. Two raised bed profiles were analyzed along with 4 other sample locations indicated by the stars, the results of which are provided in the figure along with the depth of the

- sample. Results highlighted in yellow exceed the 100 mg/kg action-level threshold set by the EPA for gardening. Photographs of the raised beds are included in Figure 13 with lead values plotted in Figure 14. Additional details on these samples can be found in the P-1-2 section of Appendix 3 62
- 13 Profile Site 4. Photographs of the raised beds mapped in Figure 12 with the augers for scale showing where the samples were collected (in the top photograph it is partially covered by vegetation). The height of both beds were approximately 7 cm. Results for the profiles are plotted in Figure 14..... 63
- 14 Profile Site 4. Lead profiles of the gardens featured in Figures 12 and 13. The vertical dashed line represents the 100 mg/kg EPA threshold for gardens. The horizontal dashed line marks the distinctive boundary between raised bed soil and local soil. Note that Pb values are below the EPA threshold for gardens in the raised beds but are exceeded in the local soil. Additional details on these samples can be found in the P-1-2 section of Appendix 3..... 64
- 15 Profile Site 5. Top portion of figure displays a Sanborn Fire Insurance Map overlain on a satellite image of a community garden. Stars indicate background samples that were collected with results displayed. Note that background Samples 1 and 2 cross the 100 mg/kg threshold at depth. Lower portion of figure is an image of the garden. The raised bed profile location is indicated by red arrows with the graphed results plotted in Figure 16. Additional details on these samples can be found in the P-1-4 section of Appendix 3..... 65
- 16 Profile Site 5. Lead profiles of the garden featured in Figures 15. Note that no portion of the profile crosses the 100 mg/kg action level threshold. This is an

	example of a garden profile that falls near a drip zone and has effectively maintained low lead values by having a height greater than root depth where no tilling has taken place. Additional details on these samples can be found in the P-1-4 section of Appendix 3	66
17	Comparison of heavy metal concentrations in soil profiles from Site 1 (for additional sample details see the P2-2 section of Appendix 3)	67
18	Comparison of heavy metal concentrations in soil profiles from Site 2 (for additional sample details see the P2-7 section of Appendix 3)	69
19	Comparison of heavy metal concentrations in soil profiles from Site 3 (for additional sample details see the P2-3 section of Appendix 3)	70
20	Comparison of heavy metal concentrations in soil profiles from Site 4 (for additional sample details see the P1-2 section of Appendix 3)	71
21	Comparison of heavy metal concentrations in soil profiles from Site 5 (for additional sample details see the P1-4 section of Appendix 3)	72
22	Average lead concentration versus depth including garden soil (in-ground and raised), soil beneath gardens, and adjacent to gardens (e.g. pathway and background samples). This contrasts with Figure 25 which focuses entirely on soil within raised beds. Note that average soil Pb concentrations peak at 31-35 cm depth.....	73
23	Average lead concentration versus depth after subtracting garden soil (resulting in a general urban soil profile). Note that average peak values are found at 25-30 cm depth which corresponds with the typical root zone.....	74

24	Average lead concentration versus age of gardens. Note a general increase in soil Pb concentration with increasing garden age.....	75
25	Average lead concentration versus garden soil thickness. Note that this figure only includes soil within the raised portion of gardens. In contrast, Figure 22 includes garden soil, soil beneath gardens, and soil adjacent to gardens (e.g. pathways and background samples). Note a significant drop in mean and maximum soil Pb concentration with greater than 20 cm garden soil thickness	76
26	Average lead concentration between in-ground and raised beds (top 30 cm of in-ground beds versus raised portion of raised beds)	77
27a	A scatterplot of Pb versus Ti values found within the 1-meter drip zones of demolished structures. An R^2 value of 0.0004 indicates that there is no significant correlation between Pb and Ti values	78
27b	A comparison between Pb and Ti profiles for the P2-2 gardens. Pb shows a gradual increase with depth, while Ti maintains far more constant values along the profiles (with a notable spike for Raised Garden 2 (P2-2-2) at 30 cm depth)	79
27c	A comparison between Pb and Ti profiles for the P2-7 gardens. Pb shows a gradual increase with depth, while Ti shows no consistent patterns	80
27d	A comparison between Pb and Ti profiles for the P2-3 gardens. Pb shows increase starting around 35 cm depth, while Ti shows variable values between the gardens .	81
27e	A comparison between Pb and Ti profiles for the P1-2 gardens. Pb increases with depth while Ti remains relatively constant	82
28	A diagram on gardening practices in urban environments with Pb contaminated soil. “Clean” indicates soil below EPA lead action levels at 100 mg/kg for garden	

soils. Non-functional liners include expired (old enough to no longer serve their purpose), incomplete, or damaged liners. Note that excavated contaminated soil before emplacement of raised gardens adds to the thickness of the “clean” soil horizon. And functional wind barriers will provide a reduced benefit if the barrier is formed from vegetation that is used for mulch 83

LIST OF TABLES

Table	Page
1 Medical risks associated with lead exposure	84
2 Predicted blood lead levels for surface soil Pb concentrations, maximum Pb found at depth, and background samples using the USEPA IEUBK modeled for children of different age groups. Total Pb from the original soil samples is listed in the right column. Predicted BLLs exceeding 5 µg/dL are highlighted along with original soil concentrations exceeding 330 mg/kg (as it sets the minimum threshold for generating a 5 µg/dL BLL prediction)	85

LIST OF APPENDICES

Figure	Page
A Questions posed to gardeners.....	87
B Total organics are represented by Weight Loss (%). Measured approx. 1 gram of each sample and heated to 375° for 16 hrs. Sample IDs ending in “S” are surface samples. Samples ending in “D” are depth samples. Samples beginning with “P” are profile samples with their depth indicated by the last number. For example, sample P2-2-1-5 is a profile sample taken at 5 cm depth	88
C Sample descriptions and data. The ICP-OES wavelengths used to determine the quantity of heavy metals were as follows: As = 1937 nm, Cd = 2265 nm, Cr = 2677 nm, Mn = 2576 nm, Ni = 2316 nm, Pb = 2203 nm, and Ti = 3349 nm with results in mg/kg. Included is the age of the garden, sample depth (cm), height of the raised bed (including depth where gardens have been excavated), the presence of liners (T=true, F=false), types of liners, and sample details	93
D Revised from Gulson et al., (1995) showing potential sources and pathways lead can reach children	101

INTRODUCTION

Lead (Pb) is a heavy metal that has been used by humanity for thousands of years, yet the full extent of its deleterious effects has only been understood quite recently. This includes its negative impact on every body system (CDC, 2018). Children, especially those in the age group of 1-2 years, are the most susceptible to lead ingestion due to instinctive hand to mouth behaviors (Lanphear and Roghmann, 1997; Abadin et al., 2007; Desmurget et al., 2014) and their higher levels of Pb absorption through their developing brain and stomach lining. Previous studies have shown children can consume up to 100 mg/day of soil. (Ljung et al. 2006). Between 2018 and the first month of 2019, 5.9% of the children less than 6 years old tested in Toledo had confirmed BLLs $>5 \mu\text{g/dL}$ (ODH, 2019). That level is set by the Center for Disease Control, but it's important to note that in children there is no currently known safe level for Pb exposure (Vorvolakos et. al, 2016; Mielke, 2016). Other sources of lead ingestion such as contaminated homegrown vegetables have been determined to account for only 3% of children's daily exposure of lead as opposed to direct soil ingestion which accounts for up to 82% of daily exposure (Clark et al., 2008).

Many anthropogenic sources of Pb such as leaded paint and gasoline have been phased out resulting in reduced blood lead levels (BLLs) compared to previous decades (Needleman, 2004; Thomas et al., 1999), but children in regions with older housing and a history of high traffic continue to have elevated BLLs. Lead exposure can also lead to brain nerve damage, hearing problems, slowed growth, digestive problems, and for adults reproductive problems (ACCLPP, 2012; EPA, 2017). Additional health hazards associated with lead as compiled by Mielke (2016) are included in Table 1. Furthermore, the U.S. Department of Education has noted

higher high school dropout rates for larger cities where higher quantities of lead are more commonly found in the soil (Mielke et al., 1989).

High concentrations of Pb in urban environments have been found to largely originate from anthropogenic sources such as Pb paint, leaded gasoline, and many industrial sources (see Johnston and Hricko, 2017 and references therein). Furthermore, large cities tend to show higher Pb concentrations in the inner-city areas (Datko-Williams et al., 2014). As for individual properties, homes in urban residential settings such as Appleton, Wisconsin have been shown to have “bulls-eye” patterns of Pb contamination extending outward significantly from the home in all directions as a direct result of Pb paint (Clark et al., 2013) placing the areas of high-risk exposure immediately adjacent to the house, particularly in drip zones. Drip zones are the 1 meter zone immediately surrounding structures containing Pb paint where it has naturally or purposefully been removed to collect in the surrounding soil. Houses in other cities have shown a similar pattern including Indianapolis, Indiana (Filippelli et al., 2005); London, England (BGS, 2017), New Orleans, Louisiana (Mielke et al., 2017), and Sydney, Australia (Birch et al., 2011). Paint is not only used for wooden structures, but also brick and other materials as well. So consideration of drip zones should extend to more than structural material.

Compared to other heavy metals, lead is relatively immobile in soil (Semlali et al., 2004). Consequently, understanding past land use practices is key to predicting Pb concentrations in the soil today. Pb paint was banned in the U.S. in 1978, but homes built before then may contain significant amounts of lead (Wiener et al., 2015). Houses that have been demolished will also leave a footprint of lead in the soil even if the structure has been removed. Past studies such as by Clark et al., 2008 have suggested that titanium (Ti) can be used as a marker for paint given that it replaced Pb when it was banned. This study will put this to the test by comparing drip

zones indicated by historical Sanborn Fire Insurance maps against trends in Ti and Pb.

Furthermore, understanding the mechanical pathways that determine the movement of Pb particles such as wind, water, and human land practices not only help predict the movement of lead, but is necessary for developing long-term remediation strategies.

Lead can follow many pathways for human exposure. Direct paths include consumption of contaminated soil from hand to mouth activities, contaminated garden food products, and water from lead pipes and solder. Inhalation of dust and fine particles is another pathway Pb can reach people (Zahran et al., 2013), some originating from working in contaminated garden spaces or tracked into the home on clothes or shoes (Gulson et al., 1994). And given that many homes have a history of leaded paint used for both interior and exterior spaces, dust resulting from physical removal or natural wear can be a prevalent source for lead both inside and outside the home. In industrialized cities dust can also be transported from nearby brownfields, where soil is exposed and prone to erosion (Forest Research, 2019). And while discrete paint chips are less likely to travel far by wind, finer particles such as those resulting from Pb gasoline or paint ground to fine particles (e.g. improper paint removal by blasting, sanding, scraping, etc.) will strongly depend on local wind patterns and whether wind barriers are present (Laidlaw and Filippelli, 2008). Unfortunately, wind patterns can be difficult to predict because it is influenced by local structures and barriers and can vary from location to location through time.

Previous studies have determined that accounting for exposure to Pb in soil may not in itself be enough to account for elevated blood Pb levels, but that indoor exposure should also be considered (Clark et al., 2008). This possibility has further been investigated in a study by Gulson et al. (1994), where samples of gutter sweepings, ceiling dust, vacuum cleaner dust, long-term dust, surface dust wipes, external and internal air, food, water, and gasoline were tested. In

the case of the Broken Hill mining community in Australia it was determined that although the predominant contributor of Pb poisoning was from the local galena (PbS) orebody, there were significant contributions from other sources such as paint, leaded gasoline, and tobacco smoke. In contrast, sources of soil Pb in the Toledo area are dominated by leaded paint and the historical use of leaded gasoline (Stewart et al., 2014). Other industrial activities can contribute Pb as well (e.g. coal storage and ash, lead-acid battery recycling, metallurgy, etc.).

Leaded gasoline in the form of tetraethyl Pb (TEL) was used as an antiknock additive from 1923 until it was banned in the United States in 1996. Railroads have also been linked to elevated Pb values (Akoto et al., 2008; Liu et al., 2009; Ma et al., 2009; Wilkomirski et al., 2011).

Simonetti et al. (2000), and Doucet and Carignan (2001) have shown that using concentrations of multiple elements can provide more precise origins of Pb. Under normal circumstances this study would focus on taking advantage of the replacement of Zinc and TiO₂ for Pb in paint as an indicator for lead source, but many gardens are placed over sites where structures were demolished before Ti could make a significant contribution to their signature. Therefore it is necessary to use historical maps such as from the Sanborn Fire Insurance company to determine sources of lead, and whether features such as historical drip zones (the one-meter zone immediately surrounding a structure containing lead paint) correspond with significant lead signatures. And given that studies such as by Schwartz et al. (2012) have shown that larger particles of lead such as those from paint tend to stay in place, it is expected that lead hotspots will be localized with background levels being dominated by finer particles such as from leaded fuel exhaust.

This study represents a continuation of previous work by Stewart et al. (2014) in the Toledo area which focused on residential soil samples from yards, schools, and play areas for children (Figure 2). But based on other studies, community gardens are also an important potential pathway of Pb exposure (Spliethoff et al., 2016; Bugdalski et al., 2014; Clark et al., 2006; Laidlaw et al., 2018, etc.). Therefore it is necessary to expand on the past work on Toledo residential soils by branching out into garden soils and the impact of gardening practices on the distribution of heavy metals, especially lead.

Factors Impacting Heavy Metals in Garden Soil

A number of factors were investigated to improve understanding of garden lead contamination including the presence of drip zones, historical land use, tilling practices and root depth, thickness of clean garden soil (e.g. having in-ground vs. raised beds), presence and quality of liners, original source of garden soil, contamination from soil barriers or compost, age of the garden, and the presence of wind barriers. A brief description of these factors is provided below:

1. The Presence of Drip Zones

Drip zones form a 1-meter buffer around a structure where paint has chipped off or worn down to collect in the local soil. Paint can also build up as a result of purposeful removal prior to adding new layers of paint. Given the use of leaded paint in the U.S. up until 1978, many locations have experienced a significant contribution over time. Stewart et al. (2014) found this source to form the strongest correlation with BLLs in children in Toledo, OH with road density coming in close second. It deserves discussion outside general historical land use because of the important role it plays for community gardens.

2. Historical Land Use

Historical land use includes anything related to the use of the property that could have impacted heavy metals contamination. This includes roadways bearing high traffic, factories, gas stations, coal storage and use, spill sites, etc.

Each location containing gardens has its own unique site history, and even within that same site the history may vary. This demonstrates the importance of small-scale investigations into lead distributions, a finding confirmed by Bechet et al. (2018) and Bugdalski et al. (2014). For example, what is now a large open space with gardens may have once had a gas station across from a house. Each type of land use comes with its own unique contribution to heavy metals. Furthermore, the people on each property may have their own peculiar land use practices. This is further compounded by variable demolition practices including where some structures are demolished with much of their rubble left in place covered by a thin layer of new soil, while other structures are demolished and partially excavated. Also, municipal work on sewers, pipelines, and other utilities further contribute to soil heterogeneity. This complexity drives the necessity for testing each garden site individually and across spaces where land use may have varied. However, common features such as drip zones and high-traffic roads are shared across many sites and can be studied in a broader sense.

Other site histories investigated in this study included schools, theaters, farmland, trainyards, auto factories, grocery stores, etc. Present and former housing by far proved the most common land-use investigated.

Key to determining site history in this study has been the use of the Sanborn Fire Insurance maps which not only helped outline the locations of former structures, but also informed on past land uses. For example, they made it easy to distinguish between housing, industrial, and other historical land uses. They have maps dating back to the 1880s and cover

approximately 12,000 cities and towns in the U.S. Not only do they provide a significant window into the legacy of past land use, but their utility is applicable to other U.S. urban areas as well.

3. Tilling Practices and Root Depth

The impact of tilling practices and root action in bringing heavy metals up to the surface is directly linked to the depth of clean garden soil. A thick clean soil profile allows for deeper tilling and root structures without directly interacting with native soil below the base of the garden.

4. Thickness of Clean Garden Soil

Having a buffer zone between clean surface garden soil and potentially contaminated local soil beneath is an effective strategy for reducing risk of lead contamination. When gardens are at ground level with no barriers there is easy exchange with soil outside the garden. But when beds are raised sufficiently to prevent this the sources of potential contamination can be reduced to windborne Pb dust particles, tilling extending below the “clean” soil horizon, and root action.

Directly related to having in-ground vs. raised beds is the depth of clean soil in the garden. Some gardens weren't raised but rather excavated at ground level before clean soil was emplaced. And while the impact was similar as for raised beds, having gardens at ground level allows for easier cross contamination with native soil if the garden boundaries are not sufficiently contained.

5. The Presence and Quality of Liners

Liners placed at the lower boundaries of garden soil can serve as a barrier to prevent contaminated soil from reaching the surface. But the effectiveness in preventing soil migration can vary depending on the quality of the material and whether it sustains damage over time.

6. The Original Source of Garden Soil

It is important to consider whether the garden contains local soil or soil transported from elsewhere. If the soil is locally sourced the concentration of Pb will reflect local conditions, but where it was imported it will reflect the conditions from where it came.

Many urban gardens are located at demolished housing sites. Determining whether the city brought in new soil or left old soil and rubble in place required questioning the gardeners or neighbors of the property as well as on-site observations such as the presence or absence of rubble. However, because there are no reliable records or memory of demolition practices, this factor is difficult to obtain.

7. Contamination from Soil Barriers or Compost

Although at low risk for contributing lead to a garden, wooden barriers of treated lumber can be a source of other heavy metals such as arsenic or copper which can leach into the garden soil. Compost material can also contaminate a garden if it itself is contaminated. Vegetation tends to bioaccumulate heavy metals, so wood chips or compost derived from local contaminated vegetation will have a negative impact on a garden.

8. Age of the Garden

The degree of contamination in a garden will increase with age and exposure as more local contaminated soil is allowed to migrate into the garden soil via wind, tilling, or root action. The older a garden, the more time lead has to mobilize and accumulate. Pb-bearing dust can significantly accumulate over time, liners can degrade, and in-ground gardens or unlined raised gardens can homogenize with local soil through tilling or natural mixing. Some gardeners reported gardens that sunk or lost surface soil as they aged, subsequently losing the buffer-zone between garden soil and native soil. Barriers around the edges of the gardens can also deteriorate over time, creating a blended boundary of garden and local soil.

Addressing garden maintenance over time also determines whether the clock was reset on any of these cumulative effects. Obtaining as much information on the gardens as possible is critical for accounting for the effects of gardening practices on soil Pb-levels.

9. Size and Source of Pb Particles

Due to the fine particulates produced in vehicle exhaust the Pb it contains is easily distributed by wind and absorbed through stomach lining. It is also readily accumulated on the surfaces of plants (Monaci et al., 2000), and absorbed into the soil along roads (Little and Wiffen, 1978). Stewart et al. (2014) showed that road density strongly correlated with BLLs in the Toledo area, and studies in other countries have shown the same trends (Davis and Birch, 2011; Wu et al., 2010).

Atmospheric aerosols reflect large-scale inputs from widespread and distant areas which will make determining Pb sources complicated (Komarek et al., 2008). Finer Pb particles will also be more strongly influenced by the presence of wind barriers.

All sources of Pb can be redistributed in the form of dust particles which can be a source of recontamination for places where measures such as those listed above have previously been taken to reduce Pb in surface soil.

Other factors impacting the presence of Pb in garden soil include precipitation, soil organic matter, clay content, etc. (Ettler et al., 2004; 2005), and pH may also play a role in Pb concentrations and bioavailability in soil (Acosta et al., 2014).

Bioavailability

Along with determining Pb soil concentrations, calculating how much of it is bioavailable is the next logical step. Bioavailability is defined as the amount of an ingested substance absorbed into the body compared to the amount available (Davis et al., 1992). Current official guidelines don't take bioavailability into account and simply place 400 mg/kg of total soil Pb as the upper range of soil where children play, and 100 mg/kg for garden soils (EPA; Final Rule, 2001). Studies that have addressed the amount of bioavailable lead versus total lead have determined that bioavailability can vary by Pb speciation, soil characteristics, and Pb sources (Davis et al., 1993; Hettiarachchi and Pierzynski, 2004; Ruby et al., 1999). A program created by the United States Environmental Protection Agency (USEPA) called Integrated Exposure Uptake Biokinetic (IEUBK) Model was used to generate an estimate of bioavailable Pb from garden soil.

METHOD AND MATERIALS

Study Area and Past Land Use

The study area incorporated urban Toledo, OH and immediately surrounding areas. Garden locations were targeted for sampling based on those found in areas demonstrating higher BLLs as determined by the 2016 Ohio State Health Assessment (Figure 1), and locations predicted to have high Pb soil based on the findings of Stewart et al. (2014) (Figure 2). The stars on Figure 2 represent locations where samples were collected for soil profiles but does not include the locations of all 27 sites that were sampled. This is for two reasons. First, it was done to help protect the security of private locations that required a high level of anonymity. Second, most sample sites only included background samples because profiles were collected only on sites demonstrating key features of interest.

Given that many community gardens are located on the sites of demolished structures it was important to determine the locations of past buildings and land use history. For this purpose the Sanborn Fire Insurance company maps were consulted. These maps date back as far as 1882 and enable current Pb soil contamination to be mapped against historical activity from housing, roads, and businesses no longer present today. The Sanborn maps can be overlain on readily available satellite imagery such as from Google Earth to reference the position of historical structures with respect to present gardens. But there are a few important limitations to applying the map overlays on satellite images; namely differences arising between hand-drawn maps and satellite images, and the distortions or low resolution of some satellite images rendering smaller gardens invisible. The latter issue is easily resolved by geolocating gardens and referencing them to the satellite image, but correcting the differences arising from a hand-drawn map is more complicated. Ultimately it requires correlating known points on the satellite image with known

points on the map which can stretch and contort it in odd ways. This was resolved by focusing on local accuracy around the garden sites for which errors could be minimized.

Determining Gardening Practices

Gaining access to gardens across Toledo was made possible through Toledo GROWS, a non-profit community garden organization which provided connections with numerous gardeners across the Toledo area. This helped both with obtaining access to diverse samples as well as providing community outreach. Of the more than 130 gardens participating in the Toledo Grows program, 27 participated in this study.

To address gardening practices, participants were questioned about the history, layout, and practices involved in their garden projects (Appendix 1). Questions asked of participants included ages of gardens, sources of garden soil and fertilizer, tilling practices, types of vegetation grown, and anything else related to gardening practices and site history. The age of gardens was determined by asking participants and confirming the information using historical satellite imagery. Gardeners were also questioned on locations of past drip zones of structures that have since been demolished, and this was combined with estimates based on the Sanborn Fire Insurance maps to determine likely locations. It should be noted that many structures had been demolished so far in the past that there was no local memory of their former location. Consequently the Sanborn Fire Insurance maps were often the primary source of historical land use information.

Determining tilling practices in urban community gardens was particularly difficult, especially so because gardeners were rarely the same for any garden year to year, and gardening practices such as tilling varied as a result. And many people who provided information on

gardening practices were in charge of sites containing many gardens with different gardeners assigned to each, and therefore had very limited knowledge on gardening practices.

Consequently tilling practices were not included in the sample details on Appendix 3, nor in any formal statistical analysis. However, there was enough information on recent gardening practices to include it in the discussion of the profiles shown in Figures 3-15.

Previous studies by Clark et al. (2006) determined that approximately five total samples of garden soil are adequate for statistical analytical protocols because of the homogenization of soil when tilling is performed. However, based on questions to gardeners and on-site observations it became apparent that diverse tilling practices were engaged across different garden locations including mechanical tilling, hand-turning soil, or no tilling at all. The other primary mechanism for mobilizing soil within the garden profile involved root action and weeding (the process of pulling out unwanted plants) which could physically bring soil clinging to roots at depth to the surface. It's also important to note that many of these gardens were part of large community projects with individual gardens undergoing different gardening practices, and gardening practices for any particular garden varying from year to year. Consequently the distribution of heavy metals brought up through the soil profile in raised beds will be a more reliable source of determining the cumulative effects of gardening practices rather than placing the focus on gardening practices for any single year. This diversity of gardening practices also underscores the need for a site-specific approach to measuring heavy metals in gardens.

Field Sampling

Two rounds of sampling were implemented collecting 399 samples across 27 sites containing multiple gardens. The first wave was performed to establish the background and

general distribution of lead and other heavy metals in gardens and incorporated surface (5 cm) and root depth (~30 cm) samples. The second wave targeted Pb hotspots located by the first phase and included profile samples with 5 cm subsamples along the entire profile.

For the first phase of sampling, a 40 cm long auger was used for each site based on the diversity of gardening practices, proximity to roads and structures, and obtaining general background samples from gardens selected at random. Background samples were collected beyond the 1-meter boundary of both present and known historical drip zones. Nearby samples were also collected outside of gardens along roadsides, pathways, and other features of interest. Most samples included both a surface sample composed of the top 5 cm, and a depth sample obtained around root depth (30-35 cm) or the maximum depth before encountering significant rubble or other obstructions.

Sites with less than five gardens were tested for each garden along with pathways, nearby roadsides, the sides of existing structures, and any other feature of interest. Sites featuring more than 5 gardens were sampled by selecting a random garden within each area of interest as well as sampling the pathways immediately adjacent to that garden. The Sanborn maps were consulted to locate sites of former structures which were sampled along their drip zones.

Once Pb-hotspots were identified, a total of five sites containing gardens were targeted for a second wave of sampling encompassing the entire soil profile up to 40 cm (or until rubble or other obstructions were encountered). Additional samples were also collected along the drip zones of sites with former structures revealed by the Sanborn maps showing elevated Pb soil values from the first phase of sampling.

To minimize cross-contamination, equipment was brushed between samples to remove soil and dust particles. Samples were also labeled with the depth they were collected and their GPS coordinate location.

Sample Preparation, Analysis, and Quality Control

Of the 399 field samples collected, a total of 218 were analyzed including 98 samples for locating and quantifying Pb hotspots and background levels, and 120 samples for 14 garden soil profiles showing elevated levels of lead.

Lead concentrations were calculated using dry weight as recommended by the USEPA (USEPA, 1993). This was accomplished by drying samples in an oven at 85° C. Samples were next homogenized with an acid-washed mortar and pestle at which point rocks, rubble, roots, and any large woodchips were removed. One gram of each sample was then subjected to an organic analysis by measuring weight loss percent placing them in a sample oven at 375° C for 16 hours (process developed by Keeling, 1962).

Heavy metals analysis of garden soil samples involved trace-metals grade acid digestion using USEPA Method 3051 A (USEPA, 2007) and subsequent analysis of dissolved heavy metals using inductively coupled plasma optical emission spectroscopy (ICP-OES) following USEPA Method 6010 C (USEPA, 2000). For quality control, acid blanks and Montana 1 standards (reference material 2710a) were included with each set of samples.

Additional aliquots were run for samples showing suspicious or unusually high Pb values. Method blanks were below detection limits for all tested heavy metals. Given these quality assurances, it was determined that the results were acceptable for interpretation and discussion.

Predictive Blood Lead Level Modeling

Bioavailability has to be assessed on a site-specific basis for any accurate analysis (Bower et al., 2017). For this purpose the EPA's Integrated Exposure Uptake Biokinetic (IEUBK) model (White and Marcus, 1998) was run for each surface sample. The utility of the IEUBK software has led to its widespread adoption and creates transparency in BLL estimates and calculations. As a model for bioaccessibility it has the benefit of adaptable parameters of Pb exposure including:

- Indoor dust Pb concentration
- Outdoor soil Pb concentration
- Food and water sources
- Daily soil ingestion
- Daily dust inhalation
- Age group being exposed (ranging between 0-7 years of age)
- Outdoor air Pb concentration
- Time spent outdoors
- Ventilation rate
- Lung Absorption
- Dietary Pb intake
- Water volume consumption and Pb concentration in drinking water
- Absorption fraction percent from soil, dust, water, diet, and other sources.

Estimates of BLLs for this study focused on surface soil lead exposure in and around gardens as they are an important source of exposure for gardeners, but it is important to note that gardeners spend significant time digging through garden soil and that soil at depth may also play an important role.

Surface soil lead values for each garden were entered into the IEUBK software for each site and calculated using the typical parameters of exposure included in the software. For example, children aged 1-4 years are expected to be exposed to a maximum combined total dust and soil intake of 0.135 g/day. Children aged 4-5 years are exposed to 0.1 g/day, aged 5-6 years exposed to 0.09 g/day, and aged 6-7 years exposed to 0.85 g/day. Outdoor air is set at a constant value of $0.1 \mu\text{g}/\text{m}^3$. Hours spent outdoors for children 1 year of age is set at 1 hr/day and increases by another hr/day for each year of age. At the ages of 4 and older, time spent outdoors reaches 4 hrs/day and remains constant with increasing age. Lung capacity is also set to increase with age starting at $2 \text{ m}^3/\text{day}$ for children aged 0-1 years and reaching $7 \text{ m}^3/\text{day}$ by the time they reach 7 years of age. All other standard values are available on the (IEUBK) model by White and Marcus (1998).

RESULTS

Comprehensive results for soil organic content are included in Appendix 2, and a full table has been attached (Appendix 3) of ICP-OES results for heavy metals including arsenic (As), cadmium (Cd), chromium (Cr), copper (Cu), manganese (Mn), nickel (Ni), lead (Pb), and titanium (Ti). Figures 3, 6, 9, 12, and 15 show Sanborn Fire Insurance maps overlain on satellite imagery along with sample locations and background results. On the maps, dots at the corners of structures indicate brick buildings while letters “D” represent dwellings, “A” warehouses, and “S” and “F” typically stores. Images of the raised beds where profile samples were collected are shown in Figures 4, 7, 10, 13, and 15. The 40 cm augers were used for scale and mark the spots where samples were collected. Figures 5, 8, 11, 14, and 16 display graphs of the profiles with EPA action levels indicated by dashed lines.

Predicted BLLs for both surface and maximum soil profile Pb values from Figures 2-13 are given in Table 2. Calculations were made for children up through 6 years of age. Soil containing a minimum of 330 mg/kg Pb was necessary to generate a BLL prediction of 5 µg/dL. Predicted BLLs are highest for children 1-2 years of age (e.g. resulting from instinctive hand-to-mouth behavior) The only surface value that exceeded the 5 µg/dL was sample 1-2-4-S. For comparison, BLL predictions were also made for maximum Pb concentrations found within soil profiles. This was done to measure the impact of potential exposure to Pb deeper in the soil as a result of gardening practices. Table 2 reveals a significant increase of predicted BLLs with exposure to Pb originating from deeper within the soil.

Organic matter (Appendix 2) showed little impact on soil lead values.

The greatest observed Pb soil concentration was 1718 mg/kg found along a drip zone at 30 cm depth. Two additional aliquots of the sample were also consistent showing 1619 mg/kg,

and 1627 mg/kg. Concentrations of Pb below 10 mg/kg were commonly found in raised beds with emplaced clean soil. Highest Pb values were often typical of drip zones (Figures 3-11), with notable exceptions being where background levels were elevated across the entire property (Figures 12-14). Lead values below layers of rubble are unknown given the volume of buried debris rendering it difficult to obtain samples beyond the upper soil layer.

A few profiles were also generated for chromium and copper. These profiles were compared to the ones found for Pb in Figures 17-21. It should be noted that the concentration profiles of Cr and Cu at Site 1 (P2-2 samples) were inverse to those of Pb. At other sample sites there were similar inconsistencies between Pb and profiles for other heavy metals. Other heavy metals including arsenic, cadmium, manganese, and nickel did not seem to produce any noticeable trends with depth in the samples that were analyzed, (e.g. Figure 17, arsenic).

All samples were combined into a single pool from which a box and whisker plot was generated comparing lead concentration over 5 cm depth intervals (Figure 22). The general trend shows an increase in mean lead concentration with depth that peaks at 31-35 cm with significant concentrations found at 36-40 cm. Figure 23 subtracts raised garden soil from the calculation to provide insight on general urban soil trends and reveals noticeable peak values at 25-30 cm followed by a downward trend.

Average lead concentration verses age (Figure 24) reveals lead values that increase with time and peak for gardens 9-10 years old and older. In addition, Figure 25 demonstrates the impact of garden soil thickness and shows a significant drop in lead concentration with gardens containing soil 20 cm and thicker.

In-ground vs raised garden lead concentrations are shown in Figure 26. In this case only the impact of Pb contamination within the root zone is considered, so only the top 30 cm is included. And for raised gardens, only soil from the raised portion of the bed is included given that the desire is to test whether it has been contaminated. Note that while mean values are similar between the two, in-ground gardens show a larger range of soil Pb concentrations. An F-Test Two-Sample for Variances with a F Critical value (one-tail) of 1.67 returned a P-value of 2.7×10^{-20} , demonstrating a strong difference in variance between the two sets of samples. This is consistent with a statistical analysis using the t-Test for Two Samples Assuming Unequal Variance with a t Critical value (two-tail) of 2.03 and t Stat of 2.765 based on a 95% confidence interval.

Figures 27a-e test whether titanium can serve as a marker for paint-derived materials (Clark et al., 2008). This is tested using a scatterplot of Ti versus Pb concentrations (Figure 27a), and profiles of Ti concentrations compared against Pb with depth (Figures 27b-e). Only gardens found within the 1 meter drip zones confirmed by the Sanborn Fire Insurance maps are included in these analyses. Figure 27a shows a scatterplot where all Ti and Pb values found within the confirmed drip zone are plotted together. The result shows no discernable trends, which is confirmed by an R^2 value of 0.0004. The soil profiles given in Figures 27b-e further confirm a lack of any recognizable patterns between Ti and Pb.

DISCUSSION

Distribution of Lead

As shown in Figures 5, 8, 11, and 14 there can be a high degree of heterogeneity along even a single drip zone, with extreme examples ranging between 155 mg/kg to more than 1700 mg/kg within the same profile depth within a single drip zone. While Pb values often peak around 20 cm below the local soil, the nature of Pb dispersal tends to vary from site to site based on past land-use practices, gardening practices, and Pb source. Heterogeneity can also result from uneven wind patterns shaped by local obstructions as well as paint removal practices. Historically it was a common practice to grind or sand old layers of paint away before applying new ones, and these finer particles would be susceptible to windborne transportation. Many pathway samples adjacent to gardens were also collected (Appendix 3, indicated under Sample Details) due to their importance as pathways of Pb exposure, especially as they often serve as play areas for children.

The characteristics most elevated Pb profiles have in common is their proximity to historical drip zones of demolished structures. There are notable exceptions including Site 4 (Figures 12-14), which may be part of a hot-zone resulting from an uneven distribution of fine Pb particles originating from automobile exhaust from Pb gasoline. The significance and extent of the distribution of Pb from automobiles in high-traffic areas is a subject deserving future study.

It is also notable that peak values for soil Pb were often found at depth. In most soil profiles (Figures 5, 8, 11, and 14) the maximum values for Pb could be found at approximately 20 cm depth (excluding the soil thickness of raised beds). Whether this correlates with the 1978 ban on Pb paint, past demolition practices, or some other historical event is unknown.

For comparison, a garden profile containing low amounts of lead has also been included (Figures 15 and 16). It is informative because it demonstrates the utility of effective gardening strategies over a drip zone that has demonstrated elevated lead values.

It should be noted that the soil Pb concentration profiles over the sites of demolished structures show a smooth rather than stepwise function of increase with depth. If structures were demolished with new soil placed on top the expectation would be that the surface layers would exhibit low Pb values until reaching the layer of rubble, at which point it would sharply increase. This smoothening may result from Pb oxide density compared to soil minerals might be causing it to sink down into the profile. Particle size will also impact this transition as larger particles (e.g. flakes of Pb paint) will be suspended in place within the soil profile while smaller particles can move more easily. The low or unpredictable solubility of Pb (McBride et al., 2005) means it will stay in the system longer but still mobilize slowly over time. The extent of this mobilization after the demolition of structures containing Pb paint deserves future research.

Sample profiles collected across the five sites are discussed in detail below:

Site 1 (Figures 3-5)

Figure 3 serves as a prime example of a site where gardening practices are directly comparable across a single drip zone. Profiles 1 and 2 represent those taken from raised gardens approximately 14 cm high lacking liners, while 3 and 4 were taken from an in-ground garden. All gardens had approximately 1 inch of surface mulch which was not included in the analysis. The star represents a background sample taken at another raised bed outside the drip zone which returned Pb values of 43 mg/kg at the surface and 54 mg/kg at 30 cm depth (Figure 3). Three aliquots were processed at 30 cm depth for Raised Bed 2 which returned an average of 1655 ± 55

mg/kg. Given the spatial distribution of elevated Pb in soil with respect to historical maps and background levels, the drip zones are obviously the primary location of contamination for this site. Figure 3 also provides a visual of the garden layout along with indicated sample locations. Figure 4 demonstrates that the raised beds combined with regular composting (organic material in Appendix 2) have made a difference in reducing surface Pb values. By comparison, the in-ground gardens start at or above the action level threshold set by the EPA immediately at their surfaces. The 100 mg/kg EPA action level for gardening is only exceeded upon entry into the local soil below the base of the raised garden, and the 400 mg/kg threshold limiting where children can play is only exceeded between 10-15 cm below the surface of local soil. This is significant because 25 cm is a common depth reachable by root structures. While the threat of exposure remains minimal while the “hot” zone lies buried, if tilling or any other soil-disturbing practices commence the elevated Pb soil is at risk of being exhumed.

Sites 2 and 3 (Figures 6-11)

Figures 6 and 9 display two more locations containing community gardens built over former residential areas. Background Pb levels (locations shown with stars) are included for reference. Images of the gardens are included in Figures 7 and 10 with the auger for scale (40 cm) also marking where samples were collected. These two garden locations allow for comparison of the effects of tilling practices over time with Site 2 containing 5 and 14-year old gardens that are tilled, and Site 3 having gardens that have only been tilled once. Results for the 5 and 14-year old gardens from the first location are included in Figure 8. Note the relatively small differences in Pb values between the 5 and 14-year old gardens. This means that only a few years of tilling was sufficient to render the Pb soil values of the 5 year old gardens

indistinguishable from the 14-year old gardens. For comparison, several of the sites from Figure 9 experienced a shallow tilling event but were sufficiently high at 16-19 cm to prevent mixing with the local soil. The result of this can be seen in Figure 11.

Initial aliquots of Site 3 revealed elevated surface values above 100 mg/kg for gardens P2-3-1 and P2-3-3 (Appendix 3). However, new surface aliquots of raised bed P2-3-1 gave reason to revise the initial data and ranged from 40-47 mg/kg, with an aliquot of raised bed P2-3-3-15 at 20 mg/kg (resulting in a corrected estimation of P2-3-3-10 of 29 mg/kg based on the average of profile values immediately above and below). Therefore it is likely that there was some error in the initial sample preparation or analysis and that the actual surface soil Pb values are well below the 100 mg/kg EPA action level threshold.

Site 4 (Figures 12-14)

Drip zones could not account for all Pb soil values above 100 mg/kg. Site 4 is among the locations that seemed to have elevated lead values outside the drip zones of historical structures. Figure 12 shows satellite imagery with a historical map overlay of a community garden located over an area that once contained drugstores that have since been demolished. Given this unique site history it is unsurprising that the quantity and distribution of heavy metals are different than for residential areas. Two profile samples were collected along the back of where the store structures would have once been. It is unknown whether Pb paint was used on site, but the roads adjacent to the property see heavy traffic which could have been an abundant source of Pb from leaded gasoline exhaust. Rubble was quickly encountered while auguring the soil for profile samples leading to an average penetrable depth of only 20 cm. This means that when the buildings were demolished, much of the rubble was likely left on site covered by a thin boundary

of soil either brought in from another location or elsewhere on site (public records do not easily resolve the source of new topsoil). Therefore any elevated concentration of Pb in the soil would have occurred after demolition or already been present in the soil that was emplaced on top of the rubble.

The gardens (shown in Figure 13) had soil raised 7 cm above the local soil and were used to grow a variety of vegetables rotated on a yearly basis. Profile samples did not cross the 100 mg/kg EPA action level threshold until reaching below the garden soil boundary (Figure 14). Interestingly, the elevated Pb values did not seem unique to any particular hot zones but were scattered across several areas of the property. A likely explanation is that the site is less influenced by paint and more so by the use of leaded gasoline from high traffic roads and parking spaces. Given that leaded gasoline contributes much smaller particles of Pb than paint, it is easier to distribute by wind across wider areas causing it to contribute more greatly to background levels. Another possibility is that demolition practices could have scattered contaminated soil in unusual directions.

Site 5 (Figures 15-16)

Site 5 demonstrates a garden with a relatively clean soil profile. While the garden (Figure 15) lacks liners, its height is 35 cm (exceeding typical root depth), and no tilling has taken place. Given that it is a 5 year old garden located near a drip zone containing elevated lead values (background samples in Figure 15) it demonstrates that maintaining a clean garden is possible in a contaminated area with the right gardening practices. However, the elevated Pb at the lower 40 cm of the profile (Figure 16) demonstrates the risk for contamination given a lack of liner and any deep soil mixing that might take place (e.g. bioturbation, tilling, etc.).

Comparison with Other Soil Lead Studies

Stewart et al. (2014) determined that age of housing and road density most strongly predicted BLLs of children in the Toledo, OH area, and given that the age of housing is associated with the duration of use for Pb paint, higher Pb values naturally follow. Studies conducted in major cities around the world also have results consistent with the contribution of housing age and density (Rouillon et al., 2016; Laidlaw et al., 2018; Pouyat et al., 2007) and roads (Al Obaidy and Al Mashhadi, 2013; Sun et al., 2010) to Pb in soils. Obstructions such as buildings also provide surfaces Pb particles can adhere to and collect in the local soil (Schwarz et al., 2012; Rouillon et al., 2016). Consequently, gardens with fences, shrubbery, and other obstructions may serve to keep windborne dust Pb particles consigned to their immediate area.

The importance of understanding site history and land use practices is well-known. For example, Bechet et al. (2018) found historical investigation into their sites helpful in understanding the distribution of lead. This study has taken this further by using historical insurance map overlays on garden satellite images to demonstrate the effects of site history on Pb levels.

Other Heavy Metals

A planned garden site with no pre-existing gardens was also investigated where the soil was tested adjacent to a railroad. The soil only showed 12 mg/kg Pb, but arsenic (As) measured over 25 mg/kg, one of the highest values for As measured in the Toledo area in this study. This is possibly a result of coal transport and other industrial materials along rail lines and deserves future investigation. Other areas showing elevated As levels include the compost and woodchips from Toledo Grows (39 mg/kg and 22 mg/kg respectively), and garden pathways covered in

woodchips (ranging 24-25 mg/kg). While background levels of arsenic in the Toledo area are already naturally elevated because of the origins of the native soil (Wanner, 2018), they typically range less than 12 mg/kg (Wanner, 2018) but can be further concentrated via bioaccumulation in plant matter. Because of bioaccumulation, compost and woodchips derived from local vegetation tended to show elevated levels of arsenic (W-chips and Compost Soil, Appendix 3). Profiles of arsenic showed no recognizable trends as sometimes highest concentrations would be at the surface, while others it would be found at various depths (Figure 17). Low soil concentrations were found for cadmium, manganese, and nickel; therefore no soil profiles were constructed for them.

Other heavy metals such as chromium and copper did have sufficiently high values for constructing profiles and are compared against Pb in Figures 17-21. In Figure 17 they have an inverse relationship to Pb, and in Figures 18-21 they show a general inconsistency with the trends found for Pb. This suggests they require different explanations for their origins and distributions than what has been given for lead. Some likely results from treated wood used as garden boundaries, but the extent of their contributions and whether there are other possible sources deserves future investigation.

Health Risk Assessment

General pathways followed by Pb for influencing children's BLLs are shown in Appendix 4 (revised from Gulson et al., 1994) and is important for understanding the diverse pathways children can be exposed to lead. Based on the results of this study, a new flowchart has been developed (Figure 28) showing pathways of Pb specific to a garden soil setting. Table 2 shows an approximation of Pb bioavailability for surface samples of each site listed in Figures

3-14. The surfaces of most garden soils had lead values insufficient for raising BLLs above the 5 µg/dL EPA action level, but risks increased significantly where gardens mixed with local contaminated soil and along exposed pathways where young children are likely to play while their parents tend to the garden. In addition, given that gardeners often dig in their gardens they can come in direct contact with soil from below the surface, creating a legitimate risk of exposure to buried Pb hotspots. As a result of this potential risk, BLLs were also calculated for maximum soil Pb concentrations to determine the consequences of exposure. As Table 2 demonstrates, this significantly increases predicted BLLs. At the very least, it highlights the hazard of exposing deeper layers of soil through unsafe gardening and general land-use practices. The effects of soil erosion carry a similar risk of exposing deeper layers and deserves future investigation.

The IEUBK model indicates that soil containing a minimum of 330 mg/kg Pb is necessary to generate a BLL prediction of 5 µg/dL, and the risk is highest for children 1-2 years of age, which is consistent with instinctive hand-to-mouth behavior that occurs for that age group (Lanphear and Roghmann, 1997; Abadin et al., 2007; Desmurget et al., 2014). Given this, it makes sense to limit areas to where children can play to below 330 mg/kg rather than the current standard of 400 mg/kg.

To put the community garden results into perspective, median levels of lead for agricultural areas in the United States is 11 mg/kg (Holmgren et al., 1993). This places much of the urban soils at far higher levels than would be expected in most natural settings. Also, given a combination of funding constraints on the part of gardeners, and lack of knowledge for mitigating garden lead contamination, most Toledo gardens lack liners as of 2019. In addition,

many raised gardens lack sufficient height to prevent root or tilling depth from bringing deeper contaminated soil to the surface.

Housing built before 1978 often incorporated the use of Pb paint. And given that many gardens are established on the sites of former housing, the impact footprints from demolished painted structures is clear. Figures 3, 6, 9, and 12 show where profile samples were collected in gardens along historical drip zones. The results for these profiles (Figures 5, 8, 11, and 14) commonly show exceedance of the 100 mg/kg action level threshold set by the EPA for garden soil. Gardens located over Pb hotspots are at elevated risk as they age because of degradation of garden boundaries and liners (where liners are even present), and mixing with local soil via tilling, root action, and bioturbation. In the case of tilling, it only takes one occurrence over a Pb hotspot to contaminate previously clean garden soil (Figures 6-8).

Given the complexity of the urban environment's influence on soils and the unique and diverse nature of individual gardening practices, it is difficult to apply any large-scale patterns that do not encompass site-specific history. Not only does each site have its own unique legacy of land use, but it tends to be diverse even within the same property. Often times gardens are placed over sites of demolished structures where the rubble has been left in place and covered by only a thin veneer of previously existing soil, yet other times the demolished structure has been partially excavated with native soil being replaced by soil from elsewhere which may or may not be contaminated depending on its source. Digging associated with underground pipelines and other utilities further complicate local conditions. Add to this that gardening practices differ from person to person (e.g. sources of garden soil, mulching practices, raised vs. in-ground beds, tilling practices, types of produce grown, etc.) and it becomes clear that only the broadest trends

can be applied in determining sources and pathways of lead contamination in an urban garden environment.

However, one thing that most Pb hotspots within garden areas have in common is their location over drip zones. Therefore locating drip zones both past and present is key to locating garden areas that are at greatest risk of Pb contamination. Other factors such as gardening practices and wind transport of Pb particles also play a role, but for contamination to take place, gardens require an initial source of Pb. With few exceptions, for gardens located away from roads the predominant source of lead contamination is the legacy of Pb paint from drip zones. And given the relative immobility of lead in soil, it is a legacy that will last far into the future without remediation.

Ranking Impact Factors of Garden Soil Lead

Based on observations from this study, the importance of factors impacting garden soil Pb have been ranked. Soil Pb contamination requires a source, otherwise even with poor gardening practices it is possible to maintain a healthy garden if gardeners happen to be lucky enough to place their gardens in areas that are not be contaminated. Consequently, lead sources are ranked higher than gardening practices when it comes to heavy metal contamination in garden soil. And gardening practices such as tilling practices and root depth vs. garden soil thickness are directly related, so they have been given the same rank.

1. **Presence of drip zones.** A comparison between the Sanborn Maps and the highest values measured in gardens indicate that the presence of drip zones is by far the most important risk factor for elevated lead in community gardens. Examples include Sites 1-5 (Figures 3-15).

2. **Proximity to roads and other historical land use.** Given the historical importance of easily distributed particulates of leaded exhaust resulting from traffic, proximity to high-traffic roads is an important factor for Pb background levels. For some sites (e.g. Profile Site 4, Figures 12-14), Pb from fuel may have even played a dominant role.
3. **Tilling practices and root depth.** Most gardens that showed elevated Pb values had been tilled or were of insufficient depth to prevent mixing from soil clinging to upended roots from weeds and garden vegetables. Examples include Profile Site 2 (Figures 6-8). Soil Pb concentration in Figure 25 drops significantly with gardens 20-25 cm thick and greater largely because most garden tilling does not extend beyond that depth. Also, with rotating gardeners and gardening practices at many of these community garden sites, the likelihood of eventual tilling is significant. It should be noted that weeding, the process of uprooting unwanted plants growing in gardens, is another pathway that soil at depth can be brought to the surface.
3. (Tied with previous) **Thickness of clean garden soil (e.g. having in-ground vs. raised beds).** Maintaining gardens of sufficient height to prevent Pb contamination from the soil below the garden is closely related to tilling practices and root depth. Figures 23-24 demonstrate that Pb increases with depth, with peak values in typical urban soil generally found within 25-30 cm depth (which happens to coincide with root depth). This places in-ground gardens and gardens with insufficiently thick soil at great risk of intersecting with soil at depth exhibiting high Pb values. Figure 25 confirms this by demonstrating that gardens with soil less than 20-25 cm thick were the primary gardens having soil Pb values higher than the 100 mg/kg threshold set by the EPA. Therefore, garden soil has to be thicker than 20-25 cm to prevent eventual Pb migration to the surface. A simple

comparison between the top 30 cm of in-ground garden soil versus the soil within raised beds (Figure 26) further corroborates the importance of having elevated garden soil. Even including raised gardens of insufficient height to prevent mixing with local soil, the maximum value of soil Pb concentration was less than 200 mg/kg. By comparison, in-ground gardens showed a much higher degree of variance with much higher peak values.

Site 1 (Figures 3-5) provides an example of the impact of having a raised bed where the soil hasn't been disturbed, while Site 2 (Figures 5-8) demonstrates the risk associated if tilling ever takes place. Sites 3 and 5 contain gardens of sufficient height to reduce the risk posed by their tilling practices.

4. **Age of the garden.** Profile Sites 2-3 (Figures 6-11) allowed for comparison the effects of tilling practices over time on soil lead values and demonstrate a rapid degeneration of soil quality even with a single instance of tilling. This was further confirmed by compiling data for all gardens sampled and measuring how soil Pb concentrations differ between age groups (Figure 24). The trends show a general increase of Pb concentration with age, with significant increases for gardens 9-10 years and older. While the significance of changing public awareness for soil Pb health hazards and evolving gardening practices (including maintenance) can't be ruled out, this is strong evidence that older gardens are at higher risk of contamination. Aging liners and garden boundaries will similarly contribute to garden contamination as they become insufficient to prevent mixing between garden and local soil.
5. **The presence and quality of liners.** Liners in good condition helped prevent mixing with local soil and reduced garden lead values wherever they were used (e.g. samples 1-

3-6, 2-6-1, and 4-1-1, Appendix 3). Given that most community gardens in the Toledo, OH area lacked liners, more data is needed to quantify their impact.

6. **The original source of garden soil.** Some gardeners indicated that they used local soil for their raised or in-ground gardens. Given that many gardens were located over Pb contaminated sites, this elevated the risk of contamination. More sites should be included in future studies to investigate how commonly this occurs in urban gardens.
7. **The presence of wind barriers.** While the contribution of wind transported Pb dust was not formally investigated in this study, if it were a significant contributing factor there should be a spike in surface Pb values in the profiles shown in Figures 3-15. This should especially be the case for gardens that are never (or rarely) tilled. However, this does not seem to be the case, suggesting that wind transport only plays a minor role in Toledo, OH. It is possible that other areas within Toledo have a higher impact from wind (especially when adjacent to brownfields), but it was not observed in this study. The presence of wind barriers is still included on this list because other studies such as by Laidlaw and Filippelli, 2008 have shown that prevailing wind directions and the presence of wind barriers contribute to Pb soil levels. Therefore properties in Toledo, OH lacking wind barriers should be considered to be at some risk of contamination from wind-blown Pb particles.

Contamination from barriers or compost is also an important consideration. While they are unlikely to be a source of lead (notable exceptions include Pb dust adhered to vegetation, Monaci et al., 2000), they have been shown to contribute to As levels through the application of

arsenic-based pesticides and bioaccumulation. Locations near railroad tracks and trainyards historically used for the transportation of coal are also at higher risk of elevated levels of arsenic.

Soil Remediation Strategies

Appendix 3 and Sites 1-5 reveal that most surface samples of gardens outside of drip zones measured below the 100 mg/kg EPA action level threshold for gardens. Gardens falling directly along drip zones were at elevated risk of Pb contamination and often had soil values exceeding the 100 mg/kg threshold. In-ground garden and exposed pathway samples were at the highest risk for Pb contamination because they provided direct exposure to potentially hazardous soil.

Clark et al. (2006) determined that most plant species have approximately 3 times more Pb in their roots than in the foliar tissue. Fruiting bodies on plants will have an even smaller ratio of Pb. These amounts of Pb are relatively minor compared to Pb exposure due to improperly washed vegetables contaminated with dust and dirt. However, direct ingestion of soil by young children is still expected to be a dominant factor for high blood Pb levels given their hand to mouth instincts resulting in either the direct consumption of soil, or Pb dust adhered to object surfaces.

Simply sprinkling small amounts of new soil, mulching, or creating grass cover are ineffective long-term strategies for reducing risk of Pb exposure (Harvey et al., 2015). It is also ineffective to focus on individual contaminated plots of land without accounting for the state of soil Pb in surrounding properties (Laidlaw et al., 2017), as wind dispersal of Pb-bearing dust and other mechanical forms of sediment movement can recontaminate previously remediated

locations from nearby contaminated areas. This can be reduced by emplacing a barrier such as fence or shrubbery to reduce dust transportation into the garden (Laidlaw and Filippelli, 2008).

One strategy for Pb remediation in soil includes phosphate treatment. However, this has been criticized because the concentrations necessary for effective treatment can cause algal blooms and eutrophication from runoff water (Conley et al., 2009). Furthermore, the strategy would require tilling which is costly over large areas; and the additional drain on global supplies of phosphorous would add risk to food productivity and global food security (Chrysochoou et al., 2007).

Biosolid composts have proven to reduce Pb bioaccessibility by changing the mineral form of Pb (Brown et al., 2012; Farfel et al., 2005). Adding food and yard waste also dilutes soil Pb while similarly reducing bioaccessibility (Attanayake et al., 2014; Defoe et al., 2014). However, there's a risk in using biosolids because they may contain other toxins. Indeed, test results on the woodchips used in pathways around several gardens in Toledo have shown elevated levels of arsenic. These levels may be due to using wood that has grown locally and bioaccumulated arsenic that already exists at elevated levels in the local soil. Arsenic in woodchips may also result from wood treated with insecticides.

Another strategy for Pb removal is phytoextraction which involves using as-yet-to-be-confirmed Pb hyperaccumulating plants, or organic compounds to solubilize and subsequently extract Pb. Due to the costs and comparably low-effectiveness of phytoextraction, phytostabilization has become the most popular strategy for Pb remediation (Binns et al., 2004). While having the downside of requiring constant maintenance, growing vegetation or adding an uncontaminated physical cover to the ground, especially along pathways between gardens where

soil may otherwise be exposed, is cost effective and easy to implement. It has also been shown to reduce exposure of soil Pb through inhalation, touch, and ingestion (Butcher, 2009).

Creating raised beds higher than root depth with synthetic geotextile liners and imported clean soil has proven very effective for reducing Pb exposure (Filippelli, 2012). Avoiding leafy vegetables that grow close to the surface (Zhou et al., 2016) and root vegetables (Alexander et al., 2006) is helpful in avoiding consumption of known Pb bio-accumulators and surfaces that Pb soil particles can adhere to. All vegetables should be carefully washed to remove any Pb dust or soil adhered to the surface (Attanayake et al., 2014).

Targeted geotextile and soil replacement have been shown to reduce BLLs in children (Mielke 2016, Spliethoff et al., 2016, Clark et al., 2008). Compared to wholesale soil replacement, this strategy will be far more affordable targeting drip zones and other areas at the highest risk of Pb contamination.

Gardening practices should also incorporate dangers from other heavy metals, especially given the risk of arsenic and other heavy metals from treated wood boundaries, wood-chips, and locally-derived plant matter. This can be accomplished by using untreated wood boundaries or brick. And rather than using woodchips along pathways to reduce exposed soil, instead using stone, brick, or grass.

Titanium as an Indicator of Lead Paint

The scatterplot comparing Ti and Pb concentrations found within the 1-meter drip zones of demolished structures in Figure 27a shows there were no significant trends between the two. The locations of these drip zones were independently confirmed by the historical Sanborn Fire Insurance maps. Soil profiles of Ti were also graphed in comparison to Pb and showed no

consistent trends with high Pb values (Figures 27b-e). These findings are in direct contrast to the hypothesis proposed by Clark et al., 2008 where Ti could serve as a reliable indicator of Pb paint. This difference may result from demolished structures being torn down before Ti could make a significant contribution to their signature; in contrast to old painted structures still present today which will be far more likely to mark that transition from Pb to Ti-based paint. However, given that many urban gardeners rely on the sites of demolished structures for space for their gardens, not being able to use Ti as an elemental marker for paint has important implications for tracing sources of Pb.

SUMMARY

Factors impacting garden soil Pb contamination found in this study include the presence of drip zones, historical land use (e.g. highly traveled roads), tilling practices, garden soil thickness, and garden age. Other important factors include the presence and quality of liners, original source of garden soil, and presence of wind-barriers (Laidlaw and Filippelli, 2008).

The sources and pathways of lead discussed here are not unique to the urban areas of Toledo, OH. The trends impacting lead contamination of urban community gardens will be consistent across other urban areas that have similar use of Pb-based paint and leaded fuel. In addition, while Ti has proven to be an unreliable indicator for determining the origins of Pb paint in this study, historical maps provide a helpful alternative. Not only do they help in locating the drip zones of demolished structures, they also provide information on past land use practices. Given that historical maps such as the Sanborn Fire Insurance maps cover over 12,000 cities and towns across the U.S., they can be referenced in other urban areas as well. This historical resource was critical in establishing a site-specific approach involving local-scale soil sampling to determine site history and predict the distribution of Pb in a highly diverse urban environment.

Soil mixing and gardening practices often put gardeners in direct contact with buried soil, therefore EPA action levels for gardening should not only consider surface soil Pb conditions but also those at depth which can be impacted by tilling and root depth. The 400 mg/kg EPA action level threshold limiting where children play should also be reduced to 330 mg/kg because the IEUBK model predicted BLLs 5 µg/dL starting at that threshold.

Given that many gardens are used over many years, sustainable gardening practices become an issue of safety. Careful planning, such as avoiding placement of gardens over drip zones and creating wind barriers, is necessary to ensuring potential pathways of lead migration

are inhibited by precautionary measures. Healthy gardening practices are also key to maintaining sustainable urban community gardens for future generations to enjoy.

REFERENCES

- Abadin, H, Ashizawa, A., Stevens, Y.-W., Lladós, F., Diamond, G., Sage, G., Citra, M., Quinones, A., Bosch, S.J., Swarts, S.G., 2007. Toxicological Profile for Lead. U.S. Public Health Service, Agency for Toxic Substances and Disease Registry, Atlanta, Georgia.
- ACCLPP (Advisory Committee on Childhood Lead Poisoning Prevention), 2012. Low level lead exposure harms children: A renewed call for primary prevention. Atlanta, GA: US Department of Health and Human Services, CDC.
http://www.cdc.gov/nceh/lead/acclpp/final_document_010412.pdf. Accessed September 28, 2015.
- Acosta, J.A., Faz, A., Martínez-Martínez, S., Arocena, J.M., 2014. Grass-induced changes in properties of soils in urban green areas with emphasis on mobility of metals. *J. Soils Sediments* 14, 819-828.
- Akoto, O., Ephraim, J.H., Darko, G., 2008. Heavy metals pollution in surface soils in the vicinity of abundant railway servicing workshop in Kumasi, Ghana. *Int. J. Environ. Res.* 2, 359-364.
- Al Obaidy, A.H.M.J., Al Mashhadi, A.A.M., 2013. Heavy metal contaminations in urban soil within Bagdad city, Iraq. *J. Environ. Prot. (Irvine,. Calif)*. 4, 72-82.
- Alexander, P.D., Alloway, B.J., Dourado, A.M., 2006. Genotypic variations in the accumulation of Cd, Cu, Pb and Zn exhibited by six commonly grown vegetables. *Environ. Pollut.* 144, 736-745.

- Attanayake, C.P., Hettiarachchi, G.M., Harms, A., Presley, D., Martin, S., Pierzynski, G.M.,
2014. Field evaluations on soil plant transfer of lead from an urban garden soil. *J. Environ. Qual.*, v. 43, 475-487. <http://dx.doi.org/10.2134/jeq2013.07.0273>.
- Bechet, B., Joimel, S., Jean-Soro, L., Hursthouse, A., Agboola, A., Leitao, T.E., Costa, H.,
Cameira, M.R., Guern, C., Schwartz, C., Lebeau, T., 2018. Spatial variability of trace
elements in allotment gardens of four European cities: assessments at city, garden, and
plot scale. *J. Soils Sed.* 13:391-406.
- BGS, 2017. London Soil Geochemistry Map Lead (Pb) [Online]. Available:
<http://www.bgs.ac.uk/downloads/start.cfm?id=2026> Accessed 2/25/2019.
- Binns, H.J, Gray, K.A., Chen, T., Finster, M.E., Peneff, N., Schaefer, P., Ovsey, V., Fernandes,
J., Brown, M., Dunlap, B., 2004. Evaluation of landscape coverings to reduce soil lead
hazards in urban residential yards: the safer yards project. *Environ. Res.* v. 96, p. 127-
138.
- Birch, G.F., Vanderhayden, M., Olmos, M., 2011. The nature and distribution of metals in soils
of the Sydney estuary catchment, Australia. *Water, Air, & Soil Pollut.* 216, 581-604.
- Bower, J. A., Lister, S., Hazebrouck, G., Perdrial, N., 2017. Geospatial evaluation of lead
bioaccessibility and distribution for site specific prediction of threshold limits. *Environ.*
Pol. 229, p. 290-299.
- Brown, S.L, Clausen, I., Chappel, M.A., Williams, A., Scheckel, K.G., Neuville, M.,
Hettiarachchi, G.M., 2012. Lead and As speciation and bioaccessibility in compost
amended contaminated soils. *J. Environ. Qual.* v. 41, 1612-1622.
- Bugdalski L., Lemke L.D., McElmurry S.P., 2014. Spatial variation of soil lead in an urban
community garden: implication for risk-based sampling. *Risk Anal* 34(1):17-27.

- Butcher, D.J., 2009. Phytoremediation of lead in soil: recent applications and future prospects. *Appl. Spectrosc. Rev.*, v. 44, 123-139.
- Centers for Disease Control and Prevention (CDC): Lead.
<https://www.cdc.gov/nceh/lead/default.htm> Accessed 10/28/18.
- Chrysochoou, M., Dermatas, D., Grubb, D.G., 2007. Phosphate application to firing range soils for Pb immobilization: the unclear role of phosphate. *J. Hazard. Mater.* v. 144, 1-14.
- Clark, H.F., Brabander, D.J., Erdil, R.M., 2006. Sources, Sinks, and Exposure Pathways of Lead in Urban Garden Soil. *J. Environ. Qual.* v. 35:2066-2074.
- Clark, H.F., Hausladen, D.M., Brabander, D.J., 2008. Urban gardens: Lead exposure, recontamination mechanisms, and implications for remediation design. *Environmental Research*, v. 107, p. 312-319.
- Clark, J.J., Knudsen, A.C., 2013. Extent, Characterization, and Sources of Soil Lead Contamination in Small-Urban Residential Neighborhoods. *J. of Environ. Qual.* v. 42:1498-1506.
- Conley, D.J., Paerl, H.W., Howarth, R.W., Boesch, D.F., Seitzinger, S.P., Havens, K.E., Lancelot, C., Likens, G.E., 2009. Controlling Eutrophication: nitrogen and phosphorus. *Science*, v. 323, 1014-1015.
- Datko-Williams, L., Wilkie, A., Richmond-Bryant, J., 2014. Analysis of U.S. soil lead (Pb) studies from 1970 to 2012: The science of the Total Environment, p. 468-469, 854-863.
- Davis, B.S., Birch, G.F., 2011. Spatial distribution of bulk atmospheric deposition of heavy metals in metropolitan Sydney, Australia. *Water Air Soil Pollut.* 214, 147-162.

- Davis, A., Ruby, M.V., and Bergstrom, P.D., 1992. Bioavailability of arsenic and lead in soils from the Butte, Montana, mining district: *Environmental Science and Technology*, v. 26, p. 461-468.
- Davis, A., Drexler, J., Ruby, M., Nicholson, A., 1993. Micromineralogy of mine wastes in relation to lead bioavailability, Butte, Montana. *Environ. Sci. Technol.* 27 (7), 1415.
- Defoe, P.P., Hettiarachchi, G.M., Benedict, C., Martin, S., 2014. Safety of gardening on lead- and arsenic-contaminated urban brownfields. *J. Environ. Qual.* v. 43, 2064-2078.
- Desmurget, M., Richard, N., Harquel, S., Baraduc, P., Szathmari, A., Mottolese, C., et al., 2014. Neural representations of ethologically relevant hand/mouth synergies in the human precentral gyrus, *PNAS*, 111, 5718-5722
www.pnas.org/cgi/doi/10.1073/pnas.1321909111. Accessed September 28, 2015.
- Doe, B.R., Delevaux, M.H., 1972. Source of lead in Southeast Missouri galena ores. *Econ Geol.* v. 67, p. 409-425.
- Doucet FJ, Carignan J., 2001. Atmospheric isotopic composition and trace metal concentration as revealed by epiphytic lichens. *Atmos Environ* v. 35:3681-90.
- Environmental Protection Agency (EPA), 2017. Protect Your Family from Lead in Your Home
<https://www.cpsc.gov/Global/Safety%20Education/Furniture%20Furnishings%20Decorations/426ProtectYourFamilyFromLeadinYourHome.pdf> Accessed 2/18/2019.
- Environmental Protection Agency (EPA) Lead; Identification of Dangerous Levels of Lead; Final Rule, Vol. 66, No. 4, Rules and Regulations (Jan 5, 2001) (to be codified at 40 CFR 745).

- Ettler V., Mihaljevic M., Komarek M., 2004. ICP-MS measurements of lead isotopic ratios in soils heavily contaminated by lead smelting: tracing the sources of pollution. *Anal Bioanal Chem*, v. 378:311-1
- Ettler V., Vanek A., Mihaljevic M., Bezdicka P., 2005. Contrasting lead speciation in forest and tilled soils heavily polluted by lead metallurgy. *Chemosphere*, v. 58:1449-59.
- Farfel, M.R., Orlova, A.O., Chaney, R.L., Lees, P.S.J., Rohde, C., Ashley, P., 2005. Biosolids compost amendment for reducing soil lead hazards: a pilot study of Orgro® amendment and grass seeding in urban yards. *Sci. Total Environ.*, v. 340, 81-95
- Filippelli, G., 2012. Garden Safe – Garden Well [Online]. Available: https://www.presbyterianmission.org/wp-content/uploads/gardensafegardenwell_guide.pdf. Accessed 2/25/2019.
- Filippelli, G.M., Laidlaw, M.A., Latimer, J.C., Raftis, R., 2005. Urban lead poisoning and medical geology: an unfinished story. *GSA Today* 15, 4-11.
- Forest Research, Erosion Control. <https://www.forestresearch.gov.uk/tools-and-resources/urban-regeneration-and-greenspace-partnership/greenspace-in-practice/benefits-of-greenspace/erosion-control/>. Accessed 4/2/2019.
- Gulson, B.L., Mizon, K.J., Law, A.J., Korsch, M.J., Davis, J.J., Howarth, D., 1994. Source and Pathways of Lead in Humans from the Broken Hill Mining Community—An Alternative Use of Exploration Methods. *Economic Geology*, v. 89, p. 889-909.
- Google Earth (Used for simple overhead images of gardens in Toledo, OH. Also used to confirm the ages of gardens).
- Hansmann W., Koppel, V., 2000. Lead isotopes as tracers of pollutants in soils. *Chem Geol.* v. 171, p. 123-144.

- Harvey, P.J., Taylor, M.P., Kristensen, I.J., Grant-Vest, S., Rouillon, M., Wu, L., Handley, H.K., 2015. Evaluation and assessment of the efficacy of an abatement strategy in a former lead smelter community, Boolaroo, Australia. *Environ. Geochem. Health* v. 3, 1-4.
- Hettiarachchi, G.M., Pierzynski, G.M., 2004. Soil lead bioavailability and in situ remediation of lead-contaminated soils: a review. *Environ. Prog.* 23 (1), 78-93.
- Holmgren, G., Meyer, M., Chaney, R., and Daniels, R., 1993. Cadmium, Lead, Zinc, Copper and Nickel in agricultural soils in the United States of America. *J Environ Qual*, 22, 335-348.
- Hunt, A., Johnston, D.L, Griffith, D.A., 2006. Mass transfer of soil indoors by track-in on footwear. *Sci. of The Total Environ.* v. 370, iss. 2-3, 360-371.
- Johnston, J.E., Hricko, A., 2017. Industrial lead poisoning in Los Angeles: anatomy of a public health failure. *Environ. Justice* 10, 162-167. <https://doi.org/10.1089/env.2017.0019>.
- Keeling, P. S., 1962. Some experiments in the low-temperature removal of carbonaceous material from clays. *Clay Min. Bull.* 28, 155-8.
- Komarek, M., Ettler, V., Chrastny, V., Mihaljevic, M., 2008. Lead isotopes in environmental sciences: A review. *Environment International*, v. 34, p. 562-577.
- Laidlaw, M.A.S., Alankarage, D.H., Reichman, S.M., Taylor, M.P., Ball, A.S., 2018. Assessment of soil metal concentrations in residential and community vegetable gardens in Melbourne, Australia. *Chemosphere* 199, 303-311.
- Laidlaw, M.A.S, Filippelli, G.M., Resuspension of Urban Soils as a Persistent Source of Lead Poisoning in Children, 2008: A Review and New Directions. *Appl. Geochem.*, 23, 2021-2039.
- Laidlaw, M.A.S., Filippelli, G.M., Brown, S., Paz-Ferreiro, J., Reichman, S.M., Netherway, P., Truskewycz, A., Ball, A.S., Mielke, H.W., 2017. Case studies and evidence-based

- approaches to addressing urban soil lead contamination. *Applied Geochemistry*, v. 83, p. 14-30
- Lanphear, B.P., Roghmann, K.J., 1997. Pathways of lead exposure in urban children. *Environ. Res.* 74, 67-73.
- Little, P., Wiffen, R.D., 1978. Emission and deposition of lead from motor exhausts –II. Airborne concentration, particle size and deposition of lead near motorways. *Atmospheric Environment* (1967). v. 12, iss. 6-7, p. 1331-1341.
- Liu, H., Chen, L.P., Ai, Y.W., Yang, X., Yu, Y.H., Zuo, Y. Bin, Fu, G.Y., 2009. Heavy metal contamination in soil alongside mountain railway in Sichuan, China. *Environ. Monit. Assess.* 152, 25-33.
- Ljung, K., Selinus, O., Otabbong, E., Berglund, M., 2006. Metal and arsenic distribution in soil particle size relevant to soil ingestion by children. *Appl. Geochem.* v. 21, p. 1613-1624.
- Ma, J.H., Chu, C.J., Li, J., Song, B., 2009. Heavy metal pollution in soils on roalroad side of zhengzhou-putain section of longxi-haizhou railroad, China project supported by the national natural science foundation of China (NO. 30570301). *Pedosphere* 19, 121-128.
- McBride, M., Sauve, S., Hendershot, W., 2005. Solubility control of Cu, Zn, Cd and Pb in contaminated soils. *European J. of Soil Sci.* v. 48:2, p. 337-346.
- Mielke, H.W., Gonzales, C.R., Smith, M.K., Mielke, P.W., 1999. The urban environment and children's health: soils as an integrator of lead, zinc, and cadmium in New Orleans, Louisiana, USA. *Environ. Res.* 81, 117-129.
- Mielke, H.W., Adams, J.L., Reagan, P.L., Mielke, P.W., 1989. Soil-dust lead and childhood lead exposure as a function of city size and community traffic flow: The case for lead

- contaminated soil abatement in Minnesota. *Environmental Geochemistry and Health*, v. 9, p. 253-271.
- Mielke, H.W., 2016. Nature and extent of metal-contaminated soils in urban environments (keynote talk). *Environ Geochem Health*, v. 38, p. 987-999.
- Mielke, H.W., Gonzales, C.R., Powel, E.T., 2017. Soil lead and Children's blood lead disparities in pre-and post-hurricane Katrina New Orleans (USA). *Int. J. Environ. Res. Public Health* 14, 407.
- Mielke, P.W., Jr., Berry, K.J., 2007. Permutation methods: A distance function approach (2nd edition). New York, NY: Springer. ISBN 978-0-387-69811-3.
- Monaci, F., Moni, F., Lanciotti, E., Grechi, D., Bargagli, R., 2000. Biomonitoring of airborne metals in urban environments: new tracers of vehicle emission, in place of lead. *Env. Pol.* 107, 327.
- Muennig, P., 2009. The social costs of childhood lead exposure in the post-lead regulation era. *Arch. Pediatr. Adolesc. Med.* 163 (9): 844-9.
- Needleman, H., 2004. Lead poisoning. *Annu Rev Med* 55: 209-222.
- Ohio 2016 State Health Assessment
<https://www.odh.ohio.gov/en/odhprograms/chss/HealthPolicy/ship/State-Health-Assessment>, Accessed 8/21/2018.
- Ohio Department of Health (ODH), Lead Data.
<http://publicapps.odh.ohio.gov/EDW/DataBrowser/Browse/LeadData>, Accessed 2/7/2019.

- Pouyat, R.V., Yesilonis, I.D., Russel-Anelli, J., Neerchal, N.K., 2007. Soil chemical and physical properties that differentiate urban land-use and cover types. *Soil Sci. Soc. Am. J.* 71, 1010.
- Rouillon, M., Harvey, P.J., Kristensen, L.J., George, S.G., Taylor, M.P., 2016. VegeSafe: A community science program measuring soil-metal contamination, evaluating risk and providing advice for safe gardening. *Environ. Pollut.* 222, 557-566.
- Ruby, M., Schoof, R., Brattin, W., Goldade, M., 1999. Advances in evaluating the oral bioavailability of inorganics in soil for use in human health risk assessment. *Environ. Sci. Technol.* 33 (21), 3697-3705.
- Sanborn Fire Insurance Maps (Ohio). <https://proxy.oplin.org:2313/> Accessed 4/18/2018.
- Schwarz, K., Pickett, S.T.A., Lathrop, R.G., Weathers, K.C., Pouyat, R.V., Cadenasso, M.L., 2012. The effects of the urban built environment on the spatial distribution of lead in residential soils. *Environ. Pollut.* 163, 32-39.
- Semlali, R.M., Dessogne, J.B., Monna, F., Bolte, J., Azimi, S., Navarro, N., Denaix, L., Loubet, M., Chateau, C., Van Oort, F., 2004. Modeling lead input and output in soils using lead isotopic geochemistry. *Environ. Sci. Technol.* 38, 1513-1521.
<https://doi.org/10.1021/es0341384>.
- Simmonetti A., Gariépy C., Carignan J., 2000. Lead and Sr Isotopic compositions of snowpack from Quebec, Canada: inferences on the sources and deposition budgets of atmospheric heavy metals. *Geochim Cosmochim Acta* v. 64:5-20.
- Spliethoff, H.M., Mitchell, R.G., Shayler, H., Marquez-Bravo, L.G., Russel-Anelli, J., Ferenz, G., McBride, M., 2016. Estimated Lead (Pb) exposures for a population of urban community gardeners. *Environ Geochem Health*, v. 38, p. 955-971.

- Stewart, L.R., Farver, J.R., Gorsevski, P.V., Miner, J.G., 2014. Spatial prediction of blood lead levels in children in Toledo, OH using fuzzy sets and the site-specific IEUBK model. *Applied Geochemistry*, v. 45, p. 120-129.
- Sun, Y., Zhou, Q., Xie, X., Liu, R., 2010. Spatial, sources and risk assessment of heavy metal contamination of urban soils in typical regions of Shenyang, China. *J. Hazard Mater.* 174, 455-462.
- Thomas, V., Socolow, R., Fanelli, J., Spiro, T., 1999. Effects of reducing lead in gasoline: an analysis of the international experience. *Environ. Sci. Technol.* 33, 4252-4254.
<https://doi.org/10.1021/es991425s>.
- U.S. Environmental Protection Agency (USEPA), 1993. Pb-based Paint Laboratory Operations Guidelines: Analysis of Pb in Paint, Dust, and Soil (Revision (1.0)). Washington, DC.
- U.S. Environmental Protection Agency (USEPA), 2000. Inductively Coupled Plasma – Mass Spectrometry. Method 6010 C, Washington, DC.
- U.S. Environmental Protection Agency (USEPA), 2007. Microwave Assisted Acid Digestion of Sediments, Sludges, Soils and Oils. Method 3051A, Washington, DC.
- U.S. Environmental Protection Agency (USEPA), 2014. Technical Review Workgroup Recommendations regarding Gardening and Reducing Exposure to Lead-Contaminated Soils, USEPA< Washington, DC.
- Vorvolakos, T., Arseniou, S., Samakouri, M., 2016. There is no safe threshold for lead exposure: A literature review. *Psychiatriki*; 27(3):204-214.
- Wanner, N., 2018. Background Concentrations of Arsenic in Ohio Soils: Sources and Influencing Factors. *Ohio J. Sci.* 118(2): 2-15

- White, P.D., Marcus, A.H., 1998. The conceptual structure of the integrated exposure uptake biokinetic model for lead in children. *Environ. Health Perspect.* 106, 1513-1530.
- Wiener, R.C., Long, D.L., Jurevic, R.J., 2015. Blood levels of the heavy metal, lead, and caries in children aged 24-72 Months: NHANES III. *Caries Res.* 49, 26-33.
- Wilkomirski, B., Sudnik-Wojcikowska, B., Galera, H., Wierzbicka, M., Malawaska, M., 2011. Railway transportation as a serious source of organic and inorganic pollution. *Water. Air. Soil Pollut.* 218, 333-345.
- Wu, J., Edwards, R., He, X. (Elaine), Liu, Z., Kleinman, M., 2010. Spatial analysis of bioavailable soil lead concentrations in Los Angeles, California. *Environ. Res.* 110, 309-317.
- Zahran, S., Mielke, H.W., McElmurry, S.P., Filippelli, G.M., Laidlaw, M.A.S., Taylor, M.P., 2013. Determining the relative importance of soil sample locations to predict risk of child lead exposure. *Environ. Int.* 60, 7-14.
- Zhou, H., Yang, W.-T., Zhou, X., Liu, L., Gu, J.-F., Wang, W.-L., Zou, J.-L., Tian, T., Peng, P.-Q, Liao, B.-H., 2016. Accumulation of heavy metals in vegetable species planted in contaminated soils and the health risk assessment. *Int. J. Environ. Res. public health* 13.

APPENDIX A. FIGURES

Figure 1. Lucas County Lead Poisoning Map (from Ohio 2016 State Health Assessment)

Confirmed elevated blood lead levels (> 5 ug/dL) per 1,000 children under age 6, by census tract (2010-2014).

Figure 2. Revised from Stewart et al., (2014) showing risk of elevated BLLs overlain by predicted BLL values for Toledo, OH. Their study showed that age of housing modeled a best fit for predicting BLL risk. Stars represent garden sample sites where profiles were collected in this study.

Figure 3. Profile Site 1. A satellite image of a property containing gardens with an overlain Sanborn Fire Insurance map showing the outline of a house formerly located at the property. The red rectangle represents a drip zone where gardens are located. Numbers 1 and 2 represent profile samples collected in raised beds, with 3 and 4 representing samples from an in-ground bed. Stars #1-2 represent raised bed samples while Star #3 represents a pathway sample. Results and depths for background samples are given in the white box on the figure. A photo of the garden is shown in Figure 4. Results are plotted in Figure 5. Additional details on these samples can be found in the P-2-2 section of Appendix 3.

Figure 4. Profile Site 1. A photograph of the garden area from Figure 3 with sample locations displayed (assistant for scale towards the left-center). Results for the profiles are plotted in Figure 5.

Figure 5. Profile Site 1. Lead profiles of the gardens featured in Figures 4 and 5. The first vertical dashed line represents the 100 mg/kg EPA threshold for gardens and the second the 400 mg/kg EPA threshold for areas children can play. The horizontal dashed line marks the boundary between raised bed soil and local soil. Three aliquots were processed at 30 cm depth for Raised Bed 2 which returned an average of 1655 ± 55 mg/kg Pb. Note that Pb values are below both EPA thresholds for the raised beds, but both are exceeded in the local soil. Additional details on these samples can be found in the P-2-2 section of Appendix 3.

Figure 6. Profile Site 2. A satellite image of a garden location with an overlain Sanborn Fire Insurance map showing the outlines of several houses formerly located here. One profile was analyzed for a 5 year old garden and three profiles for 14 year old gardens. Additional surface and depth samples were processed for the location indicated by the star (1 at surface, 1 at 32 cm depth). Images of the raised beds are given in Figure 7, with Pb results for the profiles plotted in Figure 8. Additional details on these samples can be found in the P-2-7 section of Appendix 3.

Figure 7. Profile Site 2. Photographs of the gardens with the auger for scale also indicating where the samples were collected. Results for the profiles are plotted in Figure 8.

Figure 8. Profile Site 2. Lead profiles of the gardens featured in Figures 6 and 7. The vertical dashed line represents the 100 mg/kg EPA threshold for gardens. The horizontal dashed line marks the boundary between raised bed soil and local soil. Note that Pb values are close to or exceed the EPA threshold for gardening within the raised beds and clearly exceeds the threshold upon entry into the local soil. Additional details on these samples can be found in the P-2-7 section of Appendix 3.

Figure 9. Profile Site 3. A satellite image with an overlain Sanborn Fire Insurance map showing the outline of a house formerly located at the property. Stars represent locations where non-profile samples were collected. Star #1 represents a sample analyzed for the back area behind the gardens. Star #2 is a depth sample collected on the other side of the same garden where profile samples were collected. Images for sampled gardens are shown in Figure 10 and results are plotted in Figure 11. Additional details on these samples can be found in the P-2-3 section of Appendix 3.

Figure 10. Profile Site 3. A photograph of the gardens mapped in Figure 9. Augers for scale also representing where profiles were collected. Results for the profiles are plotted in Figure 11.

Figure 11. Profile Site 3. Lead profiles of the gardens featured in Figures 9 and 10. The vertical dashed line represents the 100 mg/kg EPA threshold for gardens. The horizontal dashed line marks the boundary between raised bed soil and local soil. Initially, measurements of surface samples were elevated beyond 100 mg/kg. However, new surface aliquots of raised bed P2-3-1 ranged 40-47 mg/kg, with an aliquot of raised bed P2-3-3-15 at 20 mg/kg (resulting in a corrected estimation of P2-3-3-10 of 29 mg/kg). Additional details on these samples can be found in the P-2-3 section of Appendix 3.

Figure 12. Profile Site 4. A satellite image combined with a Sanborn Fire Insurance map showing former locations of storefronts along a well-traveled road. Two raised bed profiles were analyzed along with 4 other sample locations indicated by the stars, the results of which are provided in the figure along with the depth of the sample. Results highlighted in yellow exceed the 100 mg/kg action-level threshold set by the EPA for gardening. Photographs of the raised beds are included in Figure 13 with lead values plotted in Figure 14. Additional details on these samples can be found in the P-1-2 section of Appendix 3.

Figure 13. Profile Site 4. Photographs of the raised beds mapped in Figure 12 with the augers for scale showing where the samples were collected (in the top photograph it is partially covered by vegetation). The height of both beds were approximately 7 cm. Results for the profiles are plotted in Figure 14.

Figure 14. Profile Site 4. Lead profiles of the gardens featured in Figures 12 and 13. The vertical dashed line represents the 100 mg/kg EPA threshold for gardens. The horizontal dashed line marks the distinctive boundary between raised bed soil and local soil. Note that Pb values are below the EPA threshold for gardens in the raised beds but are exceeded in the local soil. Additional details on these samples can be found in the P-1-2 section of Appendix 3.

Figure 15. Profile Site 5. Top portion of figure displays a Sanborn Fire Insurance Map overlain on a satellite image of a community garden. Stars indicate background samples that were collected with results displayed. Note that background Samples 1 and 2 cross the 100 mg/kg threshold at depth. Lower portion of figure is an image of the garden. The raised bed profile location is indicated by red arrows with the graphed results plotted in Figure 16. Additional details on these samples can be found in the P-1-4 section of Appendix 3.

Figure 16. Profile Site 5. Lead profiles of the garden featured in Figures 15. Note that no portion of the profile crosses the 100 mg/kg action level threshold. This is an example of a garden profile that falls near a drip zone and has effectively maintained low lead values by having a height greater than root depth where no tilling has taken place. Additional details on these samples can be found in the P-1-4 section of Appendix 3.

Comparing Pb, Cr, As, and Cu Profiles (P2-2 Gardens)

Figure 17. Comparison of heavy metal concentrations in soil profiles from Site 1 (for additional sample details see the P2-2 section of Appendix 3).

Figure 17. (Cont.)

Figure 18. Comparison of heavy metal concentrations in soil profiles from Site 2 (for additional sample details see the P2-7 section of Appendix 3).

Figure 19. Comparison of heavy metal concentrations in soil profiles from Site 3 (for additional sample details see the P2-3 section of Appendix 3).

Comparing Pb, Cr, and Cu Profiles (P1-2 Gardens)

Figure 20. Comparison of heavy metal concentrations in soil profiles from Site 4 (for additional sample details see the P1-2 section of Appendix 3).

Comparing Pb, Cr, and Cu Profiles (P1-4 Gardens)

Figure 21. Comparison of heavy metal concentrations in soil profiles from Site 5 (for additional sample details see the P1-4 section of Appendix 3).

Figure 22. Average lead concentration versus depth including garden soil (in-ground and raised), soil beneath gardens, and adjacent to gardens (e.g. pathway and background samples). This contrasts with Figure 25 which focuses entirely on soil within raised beds. Note that average soil Pb concentrations peak at 31-35 cm depth.

Figure 23. Average lead concentration versus depth after subtracting garden soil (resulting in a general urban soil profile). Note that average peak values are found at 25-30 cm depth which corresponds with the typical root zone.

Figure 24. Average lead concentration versus age of gardens. Note a general increase in soil Pb concentration with increasing garden age.

Figure 25. Average lead concentration versus garden soil thickness. Note that this figure only includes soil within the raised portion of gardens. In contrast, Figure 22 includes garden soil, soil beneath gardens, and soil adjacent to gardens (e.g. pathways and background samples). Note a significant drop in mean and maximum soil Pb concentration with greater than 20 cm garden soil thickness.

Figure 26. Average lead concentration between in-ground and raised beds (top 30 cm of in-ground beds versus raised portion of raised beds).

Figure 27a. A scatterplot of Pb versus Ti values found within the 1-meter drip zones of demolished structures. An R^2 value of 0.0004 indicates that there is no significant correlation between Pb and Ti values.

Figure 27b. A comparison between Pb and Ti profiles for the P2-2 gardens. Pb shows a gradual increase with depth, while Ti maintains far more constant values along the profiles (with a notable spike for Raised Garden 2 (P2-2-2) at 30 cm depth).

Figure 27c. A comparison between Pb and Ti profiles for the P2-7 gardens. Pb shows a gradual increase with depth, while Ti shows no consistent patterns.

Figure 27d. A comparison between Pb and Ti profiles for the P2-3 gardens. Pb shows increase starting around 35 cm depth, while Ti shows variable values between the gardens.

Figure 27e. A comparison between Pb and Ti profiles for the P1-2 gardens. Pb increases with depth while Ti remains relatively constant.

Figure 28. A diagram on gardening practices in urban environments with Pb contaminated soil.

“Clean” indicates soil below EPA lead action levels at 100 mg/kg for garden soils. Non-functional liners include expired (old enough to no longer serve their purpose), incomplete, or damaged liners. Note that excavated contaminated soil before emplacement of raised gardens adds to the thickness of the “clean” soil horizon. And functional wind barriers will provide a reduced benefit if the barrier is formed from vegetation that is used for mulch.

APPENDIX B. TABLES

Table 1. Medical risks associated with lead exposure.

Irreversible fetal brain damage
Early-life Pb exposure and schizophrenia
Brain damage to the developing prefrontal cortex
Learning disabilities ($<2\mu\text{g/dL}$)
Hearing problems
Stuttering
Behavioral problems and violence
Alzheimer's disease
Schizophrenia in the era of leaded gas
Eclampsia and perhaps autism
Hypertension
All cause and cardiovascular mortality at $\geq 2 \mu\text{g/dL}$
Increased cataracts
Chronic kidney disease
Diabetes
Impaired bone synthesis and Osteoporosis
Compiled by Mielke (2016). From ACCLPP (2012) and clinical reports.

Table 2. Predicted blood lead levels for surface soil Pb concentrations, maximum Pb found at depth, and background samples using the USEPA IEUBK modeled for children of different age groups. Total Pb from the original soil samples is listed in the right column. Predicted BLLs exceeding 5 µg/dL are highlighted along with original soil concentrations exceeding 330 mg/kg (as it sets the minimum threshold for generating a 5 µg/dL BLL prediction).

Sample ID	Predicted Blood Lead Levels by Age Group (µg/dL)						Soil Pb Concentrations (mg/kg)
	0.5 to 1	1 to 2	2 to 3	3 to 4	4 to 5	5 to 6	
P2-2-1-5	1.4	1.5	1.4	1.3	1.2	1.1	45
P2-2-1-40	5.8	6.7	6.2	5.9	4.9	4.1	493
P2-2-2-5	1.6	1.8	1.7	1.6	1.4	1.2	66
P2-2-2-30	13.9	16.1	15.2	14.8	12.5	10.6	1655
P2-2-3-5	2.2	2.5	2.3	2.2	1.8	1.6	118
P2-2-3-35	9.9	11.5	10.8	10.4	8.6	7.2	1019
P2-2-4-5	3.8	4.3	4	3.8	3.1	2.6	273
P2-2-4-25	6.7	7.8	7.3	6.9	5.7	4.8	602
2-2-1-S	1.4	1.5	1.4	1.3	1.2	1	43
2-2-1-D	1.5	1.6	1.5	1.4	1.3	1.1	54
2-2-2-S	1.6	1.7	1.6	1.5	1.3	1.2	58
2-2-2-D	2.5	2.8	2.6	2.5	2.1	1.8	148
2-2-3-S	2.4	2.7	2.5	2.4	2	1.7	141
2-2-3-D	3.8	4.4	4	3.8	3.2	2.7	277
P2-7-2-5	1.5	1.7	1.6	1.5	1.3	1.1	57
P2-7-2-34	2.7	3.1	2.9	2.7	2.2	1.9	168
P2-7-3-5	2	2.2	2.1	1.9	1.6	1.4	98
P2-7-3-35	5.2	6	5.6	5.3	4.3	3.6	424
P2-7-5-5	1.7	1.9	1.7	1.6	1.4	1.2	71
P2-7-5-35	2.8	3.2	3	2.8	2.3	2	180
P2-7-4-5	2.2	2.5	2.3	2.2	1.8	1.6	120
P2-7-4-30	3.9	4.5	4.2	3.9	3.2	2.7	287
2-7-4-S	1.7	1.9	1.8	1.7	1.4	1.3	75
2-7-4-D	4.3	4.9	4.6	4.3	3.6	3	325
P2-3-1-5	2.5	2.9	2.7	2.5	2.1	1.8	152
P2-3-1-40	3.2	3.7	3.4	3.2	2.7	2.3	220
P2-3-3-5	1.3	1.4	1.3	1.3	1.1	1	38
P2-3-3-40	6.6	7.6	7.1	6.8	5.6	4.7	585
P2-3-4-5	1.3	1.4	1.3	1.2	1.1	1	33
P2-3-4-39	3.9	4.4	4.1	3.9	3.2	2.7	283
2-3-1-S	2.4	2.7	2.5	2.4	2	1.7	137

2-3-1-D	6.7	7.7	7.2	6.9	5.7	4.7	597
2-3-5-S	2.6	2.9	2.7	2.6	2.1	1.8	156
2-3-5-D	2.9	3.4	3.1	2.9	2.4	2.1	191
P1-2-1-5	1.3	1.4	1.3	1.2	1.1	1	32
P1-2-1-20	3.5	4	3.7	3.5	2.9	2.4	243
P1-2-2-5	1.6	1.8	1.7	1.6	1.4	1.2	88
P1-2-2-10	2.9	3.3	3.1	2.9	2.4	2	186
1-2-1-S	1.2	1.3	1.2	1.1	1	0.9	25
1-2-1-D	2.6	2.9	2.7	2.6	2.1	1.8	156
1-2-2-S	1.9	2.1	1.9	1.8	1.5	1.3	86
1-2-2-D	1.7	1.9	1.8	1.7	1.4	1.3	76
1-2-3-S	2.5	2.8	2.6	2.5	2.1	1.8	146
1-2-3-D	2.3	2.6	2.4	2.3	1.9	1.6	127
1-2-4-S	4.6	5.3	5	4.7	3.9	3.2	364
1-2-4-D	4	4.6	4.3	4.1	3.4	2.8	301
1-2-6-S	1.4	1.5	1.4	1.3	1.2	1	43
1-2-6-D	1.1	1.1	1.1	1	0.9	0.9	16
P1-4-2-5	1.3	1.4	1.3	1.2	1.1	1	33
P1-4-2-40	1.9	2.1	1.9	1.8	1.6	1.4	88
1-4-1-S	1.4	1.5	1.4	1.3	1.1	1	42
1-4-1-D	1.7	1.8	1.7	1.6	1.4	1.2	67
1-4-3-S	1	1.1	1	0.9	0.8	0.8	9
1-4-3-D	1.6	1.7	1.6	1.5	1.3	1.2	61
1-4-4-S	1.4	1.5	1.4	1.3	1.2	1.1	44
1-4-4-D	4.8	5.5	5.1	4.9	4	3.4	382
1-4-5-S	1.2	1.3	1.2	1.2	1	0.9	30
1-4-5-D	2.2	2.5	2.3	2.2	1.8	1.6	118

APPENDIX C. QUESTIONS POSED TO GARDENERS

- What is the age of the garden?
- Are the beds in ground or raised?
- Are liners present? If so, of what material are they made?
- Was the garden soil brought in from elsewhere? If so, where from (if known)?
- What has been used as fertilizer?
- Has soil been remediated at any time?
- Types of vegetables that have been grown? Do they have deep roots, or shallow root systems?
- Do you have any knowledge of the previous land use for the garden area?
- What are the tilling practices? Is the soil turned, and if so, what is used to do so?
What time of year does tilling take place?

APPENDIX D. TOTAL ORGANICS ARE REPRESENTED BY WEIGHT LOSS

Total organics are represented by Weight Loss (%). Measured approx. 1 gram of each sample and heated to 375° for 16 hrs. Sample IDs ending in “S” are surface samples. Samples ending in “D” are depth samples. Samples beginning with “P” are profile samples with their depth indicated by the last number. For example, sample P2-2-1-5 is a profile sample taken at 5 cm depth.

Sample ID	Crucible Weight (g)	Total Before (g)	Total After (g)	Weight Loss (%)
FW3	4.0392	5.0456	4.5979	44.49
FW4	4.0643	5.0896	4.7714	31.03
Compost w/chips	4.6687	5.522	5.1418	44.56
compost w/soil	7.5848	8.488	8.4621	2.87
road/across street-S	4.2771	5.2708	4.8503	42.32
road/across street-D	3.8929	4.8878	4.6679	22.10
farm across-S	3.7291	4.7593	4.6283	12.72
farm across-D	3.8614	4.8442	4.3667	48.59
1-1-1-S	3.936	4.9629	4.9265	3.54
1-1-1-D	4.0411	5.0409	5.0228	1.81
1-1-3-S	3.9155	4.9238	4.8225	10.05
1-1-3-D	4.0636	5.0617	5.0349	2.69
1-2-1-S	8.0461	9.0657	8.9532	11.03
1-2-1-D	4.6694	5.6519	5.6261	2.63
1-2-2-S	4.0411	5.0342	4.8697	16.56
1-2-2-D	4.0636	5.0578	4.983	7.52
1-2-3-S	4.6694	5.6747	5.4706	20.30
1-2-3-D	4.2778	5.2521	5.2317	2.09
1-2-4-S	7.404	8.4055	8.2728	13.25
1-2-4-D	4.2778	5.2722	5.2258	4.67
1-2-6-S	8.1657	9.1713	9.0755	9.53
1-2-6-D	3.8636	4.8576	4.8265	3.13
1-2-8-S	7.787	8.7701	8.6935	7.79
1-3-1-D	7.5836	8.5881	8.5572	3.08
1-3-2-S	4.0392	5.0513	4.5487	49.66
1-3-2-D	4.0643	5.0423	5.011	3.20
1-3-4-D	3.8952	4.9082	4.8709	3.68
1-4-3-S	3.7289	4.741	4.6204	11.92

1-4-3-D	3.937	4.9342	4.8369	9.76
1-3-6-S	4.6687	5.6491	5.0579	60.30
1-3-6-D	4.2771	5.283	5.1112	17.08
1-4-1-S	3.8614	4.8587	4.7542	10.48
1-4-1-D	7.5848	8.5804	8.4537	12.73
1-4-4-S	3.8929	4.8747	4.6912	18.69
1-4-4-D	3.7291	4.7245	4.5837	14.15
1-4-5-S	3.936	4.9211	4.7545	16.91
1-4-5-D	3.9155	4.9138	4.7988	11.52
1-5-1-S	8.0461	9.032	8.9272	10.63
1-5-1-D	7.404	8.407	8.3658	4.11
1-6-3-D	8.1657	9.1665	9.0329	13.35
1-6-3-D	7.787	8.79	8.6902	9.95
2-1-3-S	4.0401	5.0616	4.896	16.21
2-1-3-D	4.0646	5.0629	5.0386	2.43
2-1-6-S	4.669	5.5746	5.5293	5.00
2-1-6-D	4.2772	5.2255	5.2165	0.95
2-2-1-S	3.8631	4.8111	4.6062	21.61
2-2-1-D	7.5858	8.5415	8.4289	11.78
2-2-2-S	3.9162	4.9129	4.7338	17.97
2-2-2-D	8.0435	9.0619	8.9776	8.28
2-2-3-S	7.4031	8.4029	8.3125	9.04
2-2-3-D	8.1619	9.1629	9.1032	5.96
2-3-3-D	7.7871	8.7805	8.759	2.16
2-2-5-S	3.8946	4.8538	4.6465	21.61
2-2-5-D	3.7301	4.7363	4.678	5.79
2-3-1-S	3.9378	4.9403	4.8512	8.89
2-3-1-D	3.917	4.9157	4.8879	2.78
2-3-5-S	8.0458	9.04	8.9949	4.54
2-3-5-D	7.4037	8.4096	8.3862	2.33
2-4-1-S	8.1662	9.164	9.0898	7.44
2-4-1-D	7.7873	8.7423	8.7157	2.79
2-5-1-S	4.0399	5.0344	4.9286	10.64
2-5-1-D	4.0643	5.0606	5.0273	3.34
2-6-1-S	4.6693	5.689	5.3902	29.30
2-6-1-D	4.2771	5.2548	5.1499	10.73
2-6-3-S	3.8632	4.818	4.7064	11.69
2-6-3-D	7.586	8.5418	8.5098	3.35
2-7-4-S	3.895	4.888	4.6392	25.06
2-7-4-D	3.7323	4.7365	4.6895	4.68
3-1-2-S	3.9376	4.9266	4.6527	27.69
3-1-2-D	3.9165	4.9128	4.7234	19.01

3-2-6-S	8.0462	9.063	9.0516	1.12
3-2-6-D	7.4044	8.409	8.1854	22.26
3-3-1-S	8.1668	9.1603	8.9568	20.48
3-3-1-D	7.7869	8.7431	8.5693	18.18
3-3-2-D	4.0396	5.0455	5.0072	3.81
3-3-4-D	4.0642	5.0601	5.0144	4.59
3-3-5-D	4.6696	5.6508	5.514	13.94
3-3-11-S	4.2769	5.2061	5.1634	4.60
3-3-11-D	3.8636	4.8217	4.7948	2.81
3-3-13-D	7.5849	8.5803	8.516	6.46
3-3-16-S	3.895	4.9015	4.8266	7.44
3-3-16-D	3.7298	4.7095	4.6669	4.35
3-4-2-D	3.9374	4.9197	4.8979	2.22
3-5-1-D	3.9163	4.9475	4.9046	4.16
3-5-6-S	8.0445	9.0644	8.9951	6.79
3-6-1-D	7.4032	8.4201	8.3926	2.70
3-7-3-S	3.8636	4.8563	4.7601	9.69
4-1-1-S	8.1656	9.1406	9.0007	14.35
4-1-2-S	7.7864	8.7992	8.7228	7.54
5-1-2-S	7.5836	8.5867	8.517	6.95
6-1-1-S	3.8952	4.8893	4.8542	3.53
6-1-3-D	3.7289	4.7202	4.6828	3.77
7-1-1-S	3.937	4.9369	4.5904	34.65
7-1-1-D	3.9162	4.9338	4.9124	2.10
7-1-4-S	8.0435	9.0602	8.9376	12.06
7-1-4-D	7.4031	8.4272	8.4176	0.94
7-1-6-S	8.1619	9.1636	9.1186	4.49
7-1-6-D	7.7871	8.7891	8.7587	3.03
P2-2-1-5	4.6694	5.6616	5.5528	10.97
P2-2-1-10	4.2778	5.2704	5.1384	13.30
P2-2-1-15	3.8636	4.8678	4.7518	11.55
P2-2-1-20	7.5836	8.5865	8.4603	12.58
P2-2-1-25	3.8952	4.8925	4.7603	13.26
P2-2-1-30	3.7289	4.7211	4.5858	13.64
P2-2-1-35	3.937	4.9322	4.8582	7.44
P2-2-1-40	3.9162	4.9136	4.8781	3.56
P2-2-2-5	4.0411	5.047	4.9354	11.09
P2-2-2-10	4.0636	5.0676	4.9197	14.73
P2-2-2-15	4.6694	5.6611	5.5325	12.97
P2-2-2-20	4.2778	5.2778	5.1795	9.83
P2-2-2-25	3.8636	4.8669	4.7936	7.31
P2-2-2-30	7.5836	8.5832	8.531	5.22

P2-2-2-35	3.8952	4.8986	4.8506	4.78
P2-2-2-40	3.7289	4.7246	4.6695	5.53
P2-2-3-5	3.937	4.9282	4.8078	12.15
P2-2-3-10	3.9162	4.9201	4.817	10.27
P2-2-3-15	8.0435	9.0463	8.959	8.71
P2-2-3-20	7.4031	8.3978	8.3136	8.46
P2-2-3-25	8.1619	9.1602	9.0878	7.25
P2-2-3-30	7.7871	8.78	8.7242	5.62
P2-2-3-35	4.0411	5.0416	4.9941	4.75
P2-2-3-40	4.0636	5.0609	5.023	3.80
P2-2-4-5	8.0435	9.0505	8.86	18.92
P2-2-4-10	7.4031	8.4006	8.1994	20.17
P2-2-4-15	8.1619	9.1806	8.9774	19.95
P2-2-4-20	7.7871	8.791	8.6456	14.48
P2-2-4-25	4.0411	5.0439	4.9579	8.58
P2-2-4-30	3.8952	4.8962	4.8449	5.12
P2-2-4-35	3.7289	4.7272	4.684	4.33
P2-2-4-40	3.937	4.9307	4.8536	7.76
P1-2-1-5	4.0411	5.0437	4.8946	14.87
P1-2-1-10	4.0636	5.0641	4.9311	13.29
P1-2-1-15	4.6694	5.6791	5.5626	11.54
P1-2-1-20	8.1619	9.1616	9.1066	5.50
P1-2-2-5	3.8636	4.8617	4.7326	12.93
P1-2-2-10	7.5836	8.5809	8.4541	12.71
P1-2-2-15+	3.7289	4.7389	4.6189	11.88
P2-7-2-5	3.8952	4.8877	4.8197	6.85
P2-7-2-10	3.8952	4.8962	4.6612	23.48
P2-7-2-15	3.7289	4.7215	4.4854	23.79
P2-7-2-20	3.937	4.934	4.7195	21.51
P2-7-2-25	3.9162	4.917	4.7111	20.57
P2-7-2-30	8.0435	9.0484	8.8925	15.51
P2-7-2-34	4.6694	5.6493	5.5686	8.24
P2-7-3-5	7.4031	8.4046	8.1521	25.21
P2-7-3-10	8.1619	9.1667	8.921	24.45
P2-7-3-15	7.7871	8.7854	8.5423	24.35
P2-7-3-20	4.0411	5.0456	4.8325	21.21
P2-7-3-25	4.0636	5.0614	4.8397	22.22
P2-7-3-30	4.6694	5.6722	5.4317	23.98
P2-7-3-35	4.2778	5.2741	5.0749	19.99
P2-7-3-40	4.2778	5.2707	5.218	5.31
P2-7-4-15	3.9162	4.9142	4.7532	16.13
P2-7-4-20	8.0435	9.0419	8.9065	13.56

P2-7-4-25	7.4031	8.4031	8.3069	9.62
P2-7-4-30	8.1619	9.1663	9.1253	4.08
P2-7-4-35	7.7871	8.7856	8.7542	3.14
P2-7-4-40	3.8636	4.8454	4.8164	2.95
P2-7-5-5	4.0411	5.0492	4.8321	21.54
P2-7-5-10	4.0636	5.0621	4.8406	22.18
P2-7-5-15	4.6694	5.6696	5.4605	20.91
P2-7-5-20	4.2778	5.2755	5.0752	20.08
P2-7-5-25	3.8636	4.8621	4.7068	15.55
P2-7-5-30	7.5836	8.5817	8.3343	24.79
P2-7-5-35	7.5836	8.5846	8.5096	7.49
P2-3-1-5	4.2778	5.2776	5.1731	10.45
P2-3-1-10	3.8636	4.8876	4.7998	8.57
P2-3-1-15	7.5836	8.5954	8.5105	8.39
P2-3-1-20	3.8952	4.8901	4.8108	7.97
P2-3-1-25	3.7289	4.7067	4.6333	7.51
P2-3-1-30	3.937	4.9442	4.871	7.27
P2-3-1-35	3.9162	4.9201	4.8693	5.06
P2-3-1-40	7.7871	8.781	8.7483	3.29
P2-3-3-5	4.0411	5.0414	4.7568	28.45
P2-3-3-10	4.0636	5.0611	4.9832	7.81
P2-3-3-15	4.6694	5.6773	5.6129	6.39
P2-3-3-20	4.2778	5.2779	5.2139	6.40
P2-3-3-25	3.8636	4.8694	4.8176	5.15
P2-3-3-30	7.5836	8.5801	8.5443	3.59
P2-3-3-35	3.8952	4.8906	4.8612	2.95
P2-3-3-40	3.9162	4.9076	4.8769	3.10
P2-3-4-5	3.7289	4.7961	4.7169	7.42
P2-3-4-10	3.937	4.9473	4.8686	7.79
P2-3-4-15	3.9162	4.9911	4.8349	14.53
P2-3-4-20	8.0435	9.0418	8.9842	5.77
P2-3-4-25	7.4031	8.4038	8.341	6.28
P2-3-4-30	8.1619	9.165	9.1149	4.99
P2-3-4-35	7.7871	8.7931	8.7586	3.43
P2-3-4-39	8.0435	9.0448	9.014	3.08
P2-7-1-35	7.4031	8.4022	8.3365	6.58
P2-7-1-40	4.0636	5.0616	5.0325	2.92
P2-3-2-40	3.937	4.9381	4.9169	2.12
P1-4-1-35	7.4031	8.4016	8.3145	8.72
P1-4-1-40	8.0435	9.0494	8.9328	11.59
P1-4-2-40	8.1619	9.1604	9.0548	10.58
P1-4-3-30+	7.7871	8.7828	8.6969	8.63

Sample descriptions and data. The ICP-OES wavelengths used to determine the quantity of heavy metals were as follows: As = 1937 nm, Cd = 2265 nm, Cr = 2677 nm, Mn = 2576 nm, Ni = 2316 nm, Pb = 2203 nm, and Ti = 3349 nm with results in mg/kg. Included is the age of the garden, sample depth (cm), height of the raised bed (including depth where gardens have been excavated), the presence of liners (T=true, F=false), types of liners, and sample details.

Sample ID	As	Cd	Cr	Cu	Mn	Ni	Pb	Ti	Age (yrs)	Depth (cm)	Height (cm)	Liner	Type of Liner	Sample Details:
FW3	5.08	1.26	31.68	28.36	303.24	24.93	13.83	191.9	5	5	10	F	N/A	Toledo Grows.
FW4	4.14	1.01	17.41	23.27	274.29	11.25	27.31	242.89	5	5	10	F	N/A	Toledo Grows.
W-chips	22.07	0.85	51.08	76.79	376.38	8.29	10.28	208.3	N/A	N/A	N/A	N/A	N/A	Toledo Grows compost w/chips.
Compost Soil	39.58	1.70	25.14	34.41	531.93	23.23	122.79	147.17	N/A	5	N/A	F	N/A	Toledo Grows compost with soil.
Road S	7.67	1.44	21.34	34.46	232.11	14.75	79.80	189.45	N/A	5	0	N/A	N/A	Roadside sample/farm across from Toledo Grows.
Road D	7.10	1.19	16.48	39.23	280.72	21.01	63.55	86.482	N/A	15	0	N/A	N/A	Roadside sample/farm across from Toledo Grows.
farm S	8.15	1.35	19.75	39.30	293.73	22.86	48.19	164.37	1	5	0	F	N/A	Farm across from Toledo Grows.
farm D	25.40	1.37	21.19	26.91	415.19	19.38	51.35	251.78	1	15	0	F	N/A	
1-1-1-S	11.54	1.42	21.26	34.62	497.63	22.43	58.89	191.90	2	5	0	F	N/A	Garden center.
1-1-1-D	7.04	0.96	13.01	19.17	322.93	19.07	24.75	190.43	2	18	0	F	N/A	
1-1-3-S	11.41	1.75	47.99	32.28	440.59	48.07	64.45	242.89	N/A	5	N/A	N/A	N/A	Lawn adjacent to garden.
1-1-3-D	7.18	1.04	15.32	18.69	259.41	25.59	35.66	186.86	N/A	18	N/A	N/A	N/A	
1-2-1-S	3.24	0.88	14.10	16.17	246.98	17.34	25.50	208.30	7	5	10	F	N/A	Garden center.
1-2-1-D	5.80	1.09	14.78	14.98	289.03	23.66	156.65	214.62	7	22	10	F	N/A	
1-2-2-S	3.94	1.30	18.27	32.29	323.27	19.07	85.81	130.20	7	5	7	F	N/A	Garden center.
1-2-2-D	7.08	1.42	16.18	21.34	325.75	17.17	75.79	158.74	7	22	7	F	N/A	
1-2-3-S	6.07	1.43	15.64	38.56	304.02	12.89	146.02	177.98	7	5	7	F	N/A	Garden center.
1-2-3-D	3.77	1.14	8.95	6.58	116.32	11.60	127.05	160.73	7	39	7	F	N/A	
1-2-4-S	8.28	1.57	21.00	37.82	262.51	29.32	364.99	147.17	N/A	5	N/A	N/A	N/A	Pathway.

1-2-4-D	9.61	1.43	16.47	26.49	234.49	22.14	301.71	184.39	N/A	23	N/A	N/A	N/A	
1-2-6-S	5.33	1.20	20.37	75.40	304.67	14.69	43.61	189.45	N/A	5	N/A	N/A	N/A	Street corner.
1-2-6-D	8.96	1.36	13.86	16.26	328.73	16.18	15.96	175.18	7	20	N/A	N/A	N/A	
1-2-8-S	4.52	0.97	11.25	24.05	648.96	7.40	48.04	86.48	2	5	15	F	N/A	Hoop house (8 garden surfaces from one soil source).
1-3-1-D	2.62	0.81	8.81	8.63	81.30	33.73	11.69	180.16	4	27	15	T	Newspaper	Small garden bed.
1-3-2-S	8.41	3.15	33.73	47.17	926.57	26.55	57.51	164.37	4	5	15	T	Newspaper	Small garden bed.
1-3-2-D	3.04	0.66	11.29	7.45	234.79	19.50	12.01	251.78	4	23	15	T	Newspaper	
1-3-4-D	1.85	0.74	8.05	8.02	96.08	9.92	10.26	141.68	4	17	15	T	Newspaper	Small garden bed.
1-3-6-S	1.73	1.59	13.50	36.32	381.22	15.07	38.72	98.85	4	5	N/A	T	Fabric	Back garden against building. Heavy duty fabric liner (not chemically treated liner).
1-3-6-D	0.58	0.52	7.19	11.54	157.50	10.60	10.80	151.80	4	24	N/A	T	Fabric	
1-4-1-S	7.07	1.71	22.10	31.44	228.66	19.99	41.59	201.98	5	5	45	F	N/A	Garden near road.
1-4-1-D	10.34	1.65	29.10	28.78	399.80	31.25	66.57	297.23	5	40	45	F	N/A	
1-4-3-S	9.28	1.58	20.83	24.33	233.69	24.17	30.19	256.72	4	5	15	F	N/A	Back corner bed farthest from street and parking lot (compressible soil).
1-4-3-D	8.03	1.48	13.80	23.71	255.44	14.89	61.15	173.62	4	30	15	F	N/A	
1-4-4-S	2.12	0.79	9.30	12.59	190.23	8.44	8.99	135.10	5	5	N/A	F	N/A	Zucchini bed near parking lot.
1-4-4-D	8.81	1.97	22.48	28.45	415.44	20.31	382.41	225.30	5	26	N/A	F	N/A	
1-4-5-S	4.54	1.15	15.12	18.03	476.48	21.18	43.77	137.55	N/A	5	N/A	N/A	N/A	Pathway at base of tree near garden.
1-4-5-D	7.97	1.51	24.69	19.86	501.59	43.16	118.13	176.21	N/A	15	N/A	N/A	N/A	
1-5-1-S	16.90	2.25	30.32	19.94	641.24	30.09	22.55	227.27	N/A	5	N/A	N/A	N/A	Next to road and railroad.
1-5-1-D	25.18	2.80	44.32	20.67	395.65	34.63	12.73	171.84	N/A	40	N/A	N/A	N/A	
1-6-3-S	3.38	1.00	33.35	19.17	464.26	13.68	21.86	164.58	5	5	10	F	N/A	Front left bed closest to school.
1-6-3-D	6.97	1.31	17.20	26.77	294.97	18.96	42.96	232.61	5	25	10	F	N/A	
2-1-3-S	5.64	1.06	15.53	18.31	478.31	26.84	18.73	201.98	8	5	20	F	N/A	Older raised bed closest to school.
2-1-3-D	2.31	0.59	6.92	4.96	56.93	8.93	15.38	205.34	8	40	20	F	N/A	
2-1-6-S	2.21	0.62	7.93	5.12	70.99	15.04	17.69	202.77	N/A	5	N/A	N/A	N/A	Large central opening between gardens.
2-1-6-D	1.55	0.57	7.70	2.49	56.63	51.09	6.15	184.43	N/A	40	N/A	N/A	N/A	
2-2-1-S	4.47	1.04	15.39	24.11	278.96	33.25	42.81	180.16	9	5	20	F	N/A	Front right raised bed.
2-2-1-D	7.31	1.15	16.74	20.08	377.28	20.55	53.73	202.96	9	34	20	F	N/A	
2-2-2-S	5.94	1.38	14.31	25.47	295.59	17.20	58.40	159.53	9	5	20	F	N/A	Back left raised bed.
2-2-2-D	9.81	1.70	17.35	42.93	280.12	26.37	147.91	189.55	9	40	20	F	N/A	
2-2-3-S	9.13	1.56	15.20	25.64	293.54	23.86	140.74	178.70	N/A	5	N/A	N/A	N/A	Back right outer edge of pathway (exposed soil, former dripline of removed house).
2-2-3-D	10.64	2.06	16.91	31.32	340.54	21.88	276.51	148.52	N/A	40	N/A	N/A	N/A	
2-2-5-S	6.91	1.35	21.70	24.61	289.25	26.63	75.22	173.83	9	5	0	F	N/A	

2-2-5-D	13.49	2.48	24.50	39.26	272.19	24.17	906.70	342.89	9	40	0	F	N/A	Bed (in-ground) next to fence and former dripline.
2-3-1-S	4.05	0.83	11.03	11.46	155.12	10.06	37.55	197.45	9	5	20	F	N/A	Garden closest to parking lot near road.
2-3-1-D	7.66	3.15	15.20	33.57	225.06	21.60	597.39	249.21	9	40	20	F	N/A	
2-3-3-D	4.20	1.17	9.17	9.03	223.50	17.02	156.29	177.43	9	40	20	F	N/A	Bed close to road and farthest from parking lot.
2-3-5-S	8.01	1.40	14.46	12.04	344.25	16.37	137.86	260.28	N/A	5	N/A	N/A	N/A	Back pathway near old dripline.
2-3-5-D	4.98	1.58	11.71	130.16	207.98	12.36	191.17	204.15	N/A	40	N/A	N/A	N/A	
2-4-1-S	6.87	1.38	14.47	31.04	253.20	22.16	38.89	196.58	N/A	5	N/A	N/A	N/A	Former dripline near road.
2-4-1-D	11.79	1.92	22.05	38.26	449.33	30.24	115.91	239.53	N/A	17	N/A	N/A	N/A	
2-5-1-S	5.55	1.09	14.01	17.17	259.25	13.81	15.72	156.38	9	5	6	F	N/A	Front right bed near parking lot.
2-5-1-D	4.50	0.88	12.99	8.05	150.82	13.17	12.32	184.31	9	26	6	F	N/A	
2-6-1-S	4.26	1.07	31.31	28.32	315.88	15.59	40.45	197.17	9	5	61	T	Fabric	Old bed second from right.
2-6-1-D	9.19	1.43	20.37	21.24	371.12	17.52	26.63	161.64	9	13	61	T	Fabric	
2-6-3-S	12.18	1.50	17.14	20.79	401.21	14.68	76.24	185.22	9	5	N/A	F	N/A	Raspberry bed (in-ground) at front.
2-6-3-D	18.93	2.87	23.56	17.37	1004.95	24.23	70.11	198.62	9	16	N/A	F	N/A	
2-7-4-S	4.46	1.28	23.56	28.85	404.52	11.48	74.55	147.63	5	5	15	F	N/A	Outer ring garden right at entrance.
2-7-4-D	10.81	2.52	28.34	39.69	445.75	28.22	324.52	181.54	5	32	15	F	N/A	
3-1-2-S	2.80	1.00	13.59	22.35	319.74	13.23	15.23	159.82	4	5	N/A	F	N/A	Left inside corner next to building and sidewalk.
3-1-2-D	1.12	0.64	8.58	5.40	154.14	10.16	9.12	162.51	4	25	N/A	F	N/A	
3-2-6-S	25.18	1.65	29.52	83.31	184.24	7.76	15.25	-	N/A	5	N/A	N/A	N/A	Pathway sample.
3-2-6-D	24.23	1.61	22.96	40.12	183.84	6.40	15.46	-	N/A	13.5	N/A	N/A	N/A	
3-3-1-S	4.43	1.52	19.02	16.15	297.31	14.56	14.52	-	N/A	5	N/A	N/A	N/A	1st Garden Location: Front left near road. Roadside sample.
3-3-1-D	3.18	1.21	11.90	14.54	164.27	12.95	13.39	-	N/A	23	N/A	N/A	N/A	
3-3-2-D	0.12	0.60	4.28	3.62	43.96	12.66	2.45	-	3	30	23.5	F	N/A	Left side middle. Middle of bed.
3-3-4-D	0.50	0.62	4.32	4.40	48.73	15.51	4.50	-	3	24	23.5	F	N/A	Far back right near driveway. Right edge of garden.
3-3-5-D	3.93	1.34	12.03	13.75	272.40	50.05	23.29	-	3	12.5	N/A	F	N/A	Raspberry bed (middle) rubble encountered.
3-3-11-S	12.26	2.67	22.72	19.40	347.59	48.63	23.54	-	3	5	N/A	N/A	N/A	2nd garden: Treated wood boundary strawberry garden pathway along dripline of demolished housing.
3-3-11-D	14.08	1.60	24.46	18.01	360.49	44.26	18.07	173.89	3	26	N/A	N/A	N/A	
3-3-13-D	7.36	1.05	17.22	18.27	332.40	23.41	30.57	176.30	3	23	12.5	F	N/A	3rd garden: Side of bed closest to street corner. 1.5 inch layer of woodchips on top. Treated wood boundary.

3-3-16-S	7.27	1.18	24.21	34.34	248.23	25.69	100.29	168.16	3	5	N/A	N/A	N/A	3rd garden: Lawn sample just inside fence at street corner.
3-3-16-D	7.13	1.29	23.11	34.15	269.82	26.01	106.22	208.10	3	15	N/A	N/A	N/A	
3-4-2-D	8.19	1.14	15.28	11.94	350.49	19.27	15.40	206.13	N/A	25	N/A	N/A	N/A	Back right corner just inside fence.
3-5-1-D	9.95	1.31	20.31	17.42	373.88	21.66	21.92	182.45	20	19	30.5	F	N/A	Biggest in-ground garden. Middle area. Corner near path.
3-5-6-S	10.79	1.48	24.15	22.63	417.95	21.36	35.00	231.62	20	5	N/A	F	N/A	Front middle bed near sidewalk next to road.
3-6-1-D	22.57	2.08	31.96	25.45	282.65	33.90	13.68	175.97	22	31	N/A	F	N/A	Front left near "cold frame".
3-7-3-S	14.49	1.63	16.59	77.42	342.89	22.60	125.71	238.54	4	5	N/A	F	N/A	Possible dripline (side of house)
4-1-1-S	10.57	1.36	21.24	19.78	374.10	21.72	20.10	230.63	1	5	20.5	T	Fabric	Raised bed sample. Very compressible soil.
4-1-2-S	4.85	0.79	12.56	11.74	257.75	13.07	15.53	198.62	1	5	N/A	T	Fabric	In-ground adjacent to building. Tilled 5-6 in. deep.
5-1-2-S	5.03	0.70	10.51	13.70	159.55	9.87	22.64	249.60	N/A	5	65	T	Plastic	Pathway sample (woodchips collected separately).
6-1-1-S	6.36	1.03	65.94	24.21	154.75	15.36	24.84	174.11	N/A	5	N/A	N/A	N/A	Roadside across from parking lot (high traffic)
6-1-3-D	8.10	1.02	16.98	14.59	169.92	16.07	13.36	226.48	6	26	22	F	N/A	Garden closest to school inner corner.
7-1-1-S	2.55	1.15	79.83	23.79	632.12	16.55	22.92	164.51	7	5	N/A	F	N/A	Front corner near parking lot. Clay depth. Organic surface.
7-1-1-D	6.13	1.04	13.52	12.73	319.53	20.19	20.05	173.77	7	28	N/A	F	N/A	
7-1-4-S	8.93	1.08	15.12	17.11	290.34	23.24	23.62	203.95	7	5	N/A	F	N/A	Dripline next to house. From 60's to 90's used to be painted. Next to sidewalk leading into apartment.
7-1-4-D	4.16	0.97	9.85	8.71	202.51	12.49	9.55	181.23	7	40	N/A	F	N/A	
7-1-6-S	3.13	1.30	25.49	29.27	225.99	15.07	223.20	178.64	N/A	5	N/A	N/A	N/A	Property front adjacent to road. Between road and sidewalk.
7-1-6-D	3.19	1.09	15.63	22.42	198.49	13.23	197.07	231.62	N/A	16	N/A	N/A	N/A	
P2-2-1-5	11.87	9.29	47.80	131.95	385.23	42.30	44.86	165.18	9	5	13.5	F	N/A	Inner edge of raised bed closest to street.
P2-2-1-10	11.80	5.89	35.13	88.61	397.89	42.91	44.49	98.81	9	10	13.5	F	N/A	
P2-2-1-15	11.05	6.49	37.89	99.80	410.99	38.19	62.50	139.92	9	15	13.5	F	N/A	
P2-2-1-20	13.05	5.75	36.89	85.39	418.74	37.52	65.14	144.51	9	20	13.5	F	N/A	
P2-2-1-25	12.09	3.48	26.87	47.36	377.43	30.71	113.98	120.26	9	25	13.5	F	N/A	
P2-2-1-30	8.83	1.81	18.64	27.53	286.42	21.29	154.62	225.69	9	30	13.5	F	N/A	
P2-2-1-35	8.43	2.27	19.51	29.15	335.18	24.81	390.68	182.92	9	35	13.5	F	N/A	
P2-2-1-40	8.50	2.40	16.59	26.31	428.83	26.03	493.80	178.91	9	40	13.5	F	N/A	

P2-2-2-5	6.93	5.10	29.28	82.03	309.15	23.08	65.91	148.14	9	5	14	F	N/A	Inner edge of raised bed farthest from street.
P2-2-2-10	6.11	5.79	27.95	91.02	303.67	24.16	87.07	130.93	9	10	14	F	N/A	
P2-2-2-15	7.74	5.92	28.77	72.87	406.68	21.02	148.41	205.34	9	15	14	F	N/A	
P2-2-2-20	8.92	2.02	17.01	30.43	372.25	16.87	364.05	171.52	9	20	14	F	N/A	
P2-2-2-25	9.76	2.76	17.09	35.80	271.43	16.33	730.77	186.50	9	25	14	F	N/A	
P2-2-2-30	14.20	3.99	20.61	43.49	321.69	23.04	1617.21	267.19	9	30	14	F	N/A	
P2-2-2-30(a) Aliquot	14.46	3.76	26.43	42.29	295.86	19.82	1627.70	522.33	9	30	14	F	N/A	
P2-2-2-30(b) Aliquot	15.28	4.13	23.54	45.69	346.72	20.50	1718.63	543.48	9	30	14	F	N/A	
P2-2-2-35	12.09	3.54	17.69	39.09	332.33	25.50	897.08	171.15	9	35	14	F	N/A	
P2-2-2-40	11.02	3.46	17.31	34.35	297.20	19.59	994.83	197.19	9	40	14	F	N/A	In-ground garden closest to P2-2-2.
P2-2-3-5	5.81	1.38	13.18	25.47	244.91	18.28	117.74	170.38	9	5	N/A	F	N/A	
P2-2-3-10	7.54	1.51	14.21	29.53	232.24	40.80	196.80	151.84	9	10	N/A	F	N/A	
P2-2-3-15	10.58	1.87	19.43	30.86	346.50	28.32	249.45	248.81	9	15	N/A	F	N/A	
P2-2-3-20	8.41	1.84	17.15	28.08	373.50	31.33	272.22	153.36	9	20	N/A	F	N/A	
P2-2-3-25	11.04	2.22	19.82	33.44	296.47	24.90	410.06	214.82	9	25	N/A	F	N/A	
P2-2-3-30	12.65	3.33	21.83	41.72	298.68	43.75	922.79	211.07	9	30	N/A	F	N/A	
P2-2-3-35	11.65	3.74	19.69	43.83	307.42	43.35	1019.09	207.71	9	35	N/A	F	N/A	In-ground garden farthest from street.
P2-2-3-40	9.42	3.42	17.35	31.30	233.87	27.40	669.77	198.42	9	40	N/A	F	N/A	
P2-2-4-5	9.55	1.57	28.78	33.54	342.36	15.37	271.50	209.29	9	5	N/A	F	N/A	
P2-2-4-10	10.56	1.61	23.11	37.19	330.42	18.17	278.99	156.54	9	10	N/A	F	N/A	
P2-2-4-15	11.89	1.62	28.53	37.81	341.18	18.00	267.96	174.13	9	15	N/A	F	N/A	
P2-2-4-20	10.33	1.44	22.14	30.20	318.75	18.65	171.54	193.16	9	20	N/A	F	N/A	
P2-2-4-25	15.40	2.50	25.69	44.00	347.64	23.52	601.91	248.42	9	25	N/A	F	N/A	
P2-2-4-30	17.71	2.84	16.17	35.81	386.01	18.81	484.72	338.14	9	30	N/A	F	N/A	5 gardens in from side street. From other street oriented just left of the bus stop. Sample taken from edge corner.
P2-2-4-35	15.54	2.41	14.66	33.93	291.63	15.95	472.68	387.75	9	35	N/A	F	N/A	
P2-2-4-40	13.34	3.64	13.80	79.06	246.27	16.14	516.83	293.87	9	40	N/A	F	N/A	
P1-2-1-5	3.28	0.64	10.81	10.63	142.33	33.09	31.66	221.54	7	5	7	F	N/A	
P1-2-1-10	3.30	0.68	10.63	10.16	217.65	20.59	36.57	202.96	7	10	7	F	N/A	Next bed just north of previous sample. Taken from edge corner on bus-stop side.
P1-2-1-15	8.06	1.23	21.27	37.09	347.59	18.46	143.08	221.54	7	15	7	F	N/A	
P1-2-1-20	7.96	1.57	17.88	28.89	328.84	21.73	243.10	163.58	7	20	7	F	N/A	
P1-2-2-5	7.84	1.29	13.99	63.39	314.12	14.54	87.51	212.06	7	5	7	F	N/A	
P1-2-2-10	8.21	1.30	11.31	66.24	298.64	14.52	186.48	244.27	7	10	7	F	N/A	
P1-2-2-15+	7.67	1.16	22.88	58.47	361.42	19.29	110.06	220.36	7	17	7	F	N/A	

P2-7-2-5	8.39	1.14	16.81	19.16	440.65	17.19	56.71	343.87	5	5	15	F	N/A	Garden #19. Outer ring next to garden #18. Corner of garden sampled.
P2-7-2-10	8.21	1.58	19.18	43.86	303.42	17.51	123.63	294.86	5	10	15	F	N/A	
P2-7-2-15	8.18	1.49	25.12	42.32	315.87	18.33	102.96	271.54	5	15	15	F	N/A	
P2-7-2-20	7.47	1.43	14.68	42.62	287.12	20.57	105.20	225.69	5	20	15	F	N/A	
P2-7-2-25	7.44	1.42	15.91	42.16	294.94	22.91	107.94	220.16	5	25	15	F	N/A	
P2-7-2-30	7.60	1.40	16.26	41.68	320.13	22.79	119.71	259.49	5	30	15	F	N/A	
P2-7-2-34	7.79	1.67	21.00	47.49	323.24	22.20	167.56	224.90	5	34	15	F	N/A	Garden #6. Inner ring garden. Sampled from edge farthest from tree/shrub.
P2-7-3-5	8.21	1.62	13.60	53.67	305.63	16.13	97.62	227.47	14	5	15	F	N/A	
P2-7-3-10	7.31	1.47	11.63	50.06	277.91	16.55	99.18	203.75	14	10	15	F	N/A	
P2-7-3-15	7.73	1.50	13.10	54.51	291.85	16.47	104.67	245.85	14	15	15	F	N/A	
P2-7-3-20	8.69	1.54	15.28	55.92	304.39	18.18	106.68	283.99	14	20	15	F	N/A	
P2-7-3-25	8.58	2.11	138.56	48.38	1341.88	16.26	99.11	353.36	14	25	15	F	N/A	
P2-7-3-30	8.09	1.53	23.84	45.02	346.14	16.60	142.52	288.14	14	30	15	F	N/A	Garden #10. Inner ring garden. Sampled from edge farthest from trees.
P2-7-3-35	9.33	1.71	20.17	35.40	358.44	19.71	424.49	229.05	14	35	15	F	N/A	
P2-7-3-40	13.10	1.69	22.54	28.22	516.77	31.18	161.82	225.30	14	40	15	F	N/A	
P2-7-4-5	12.1	2.20	28.59	49.83	1008.19	29.67	131.10	528.66	14	5	13	F	N/A	
P2-7-4-10	11.3	1.99	25.46	50.78	391.29	22.40	136.09	407.91	14	10	13	F	N/A	
P2-7-4-15	9.13	1.60	16.78	42.76	368.71	17.30	119.60	326.28	14	15	13	F	N/A	
P2-7-4-20	8.50	1.51	41.49	37.82	313.71	16.81	113.07	335.18	14	20	13	F	N/A	Garden #13. Inner ring garden. Has been tilled. Sampled middle south edge just inside little fence.
P2-7-4-25	7.93	1.38	14.30	36.25	265.43	16.93	143.37	244.66	14	25	13	F	N/A	
P2-7-4-30	8.15	1.39	10.40	33.58	232.36	14.39	286.66	305.14	14	30	13	F	N/A	
P2-7-4-35	8.41	1.42	9.19	33.45	237.62	14.82	260.00	274.51	14	35	13	F	N/A	
P2-7-4-40	7.88	1.21	16.27	22.42	364.63	19.16	91.01	218.97	14	40	13	F	N/A	
P2-7-5-5	5.22	1.24	28.24	31.88	355.45	11.78	70.35	330.63	14	5	10	F	N/A	
P2-7-5-10	6.27	1.45	32.12	36.64	384.18	40.49	91.07	334.19	14	10	10	F	N/A	Far right garden closest to road. Sampled from middle-right half of garden. Strange powdery white layer at lower boundary. Much leaf matter at surface.
P2-7-5-15	6.49	1.41	36.81	34.53	381.89	23.56	96.40	371.74	14	15	10	F	N/A	
P2-7-5-20	5.84	1.30	34.76	33.43	347.38	18.46	84.10	350.79	14	20	10	F	N/A	
P2-7-5-25	8.02	1.59	43.62	40.66	449.27	20.86	126.87	497.63	14	25	10	F	N/A	
P2-7-5-30	8.17	1.47	29.86	42.39	384.80	14.10	96.19	263.83	14	30	10	F	N/A	
P2-7-5-35	6.12	1.27	17.77	41.02	266.69	19.75	180.05	203.75	14	35	10	F	N/A	
P2-3-1-5	7.39	1.24	21.78	44.13	347.90	18.42	151.94	154.51	3	5	16	F	N/A	
P2-3-1-5 Aliquot	6.03	0.85	11.64	12.17	175.46	34.04	47.23	508.89	3	5	16	F	N/A	
P2-3-1-10	8.85	1.27	25.39	43.04	348.58	18.72	155.71	243.08	3	10	16	F	N/A	
P2-3-1-10 Aliquot	6.55	1.08	11.12	13.89	253.50	20.25	40.35	418.77	3	10	16	F	N/A	
P2-3-1-15	4.42	0.71	11.90	11.76	159.30	23.67	37.11	220.95	3	15	16	F	N/A	
P2-3-1-20	4.61	1.01	11.00	13.22	277.59	23.90	37.36	140.06	3	20	16	F	N/A	

P2-3-1-25	4.56	0.76	9.88	12.12	145.42	21.34	38.08	197.33	3	25	16	F	N/A	
P2-3-1-30	4.53	0.83	10.10	13.22	271.93	20.03	37.89	182.33	3	30	16	F	N/A	
P2-3-1-35	4.52	0.84	9.59	11.82	144.20	15.62	53.37	192.06	3	35	16	F	N/A	
P2-3-1-40	2.98	1.32	10.51	20.56	127.72	14.39	220.02	181.66	3	40	16	F	N/A	
P2-3-3-5	3.79	0.90	10.79	13.86	130.78	8.28	38.28	244.27	9	5	20	F	N/A	Far right corner garden. White layer at lower profile (37 cm).
P2-3-3-10	4.24	1.25	13.72	14.78	202.47	9.81	102.09	227.08	9	10	20	F	N/A	
P2-3-3-15	5.82	1.66	14.90	20.18	199.56	12.88	190.16	265.02	9	15	20	F	N/A	
P2-3-3-15 Aliquot	7.21	0.97	12.05	13.90	341.23	8.77	19.88	385.57	9	15	20	F	N/A	
P2-3-3-20	5.63	0.70	22.23	29.40	199.40	8.79	11.81	158.54	9	20	20	F	N/A	
P2-3-3-25	2.73	0.71	9.15	11.70	117.75	7.41	15.42	189.37	9	25	20	F	N/A	
P2-3-3-30	4.28	0.92	11.96	11.64	351.91	8.14	17.14	230.83	9	30	20	F	N/A	
P2-3-3-35	6.11	2.53	14.08	24.26	223.35	12.93	341.09	229.84	9	35	20	F	N/A	
P2-3-3-40	6.84	4.19	16.34	22.09	297.35	14.23	584.71	281.82	9	40	20	F	N/A	Far left corner. Sampled from middle-left (just left of center). No white layers present.
P2-3-4-5	3.95	0.91	12.54	13.43	162.30	28.99	32.55	211.66	9	5	17.5	F	N/A	
P2-3-4-10	3.83	0.86	10.82	12.70	150.13	28.52	37.65	209.88	9	10	17.5	F	N/A	
P2-3-4-15	6.19	0.91	12.83	13.89	167.50	26.59	46.20	436.17	9	15	17.5	F	N/A	
P2-3-4-20	6.16	0.86	11.69	12.25	148.95	19.78	35.09	419.76	9	20	17.5	F	N/A	
P2-3-4-25	5.57	0.87	10.02	12.74	138.57	14.04	47.43	278.66	9	25	17.5	F	N/A	
P2-3-4-30	7.69	1.17	17.23	14.48	157.26	19.62	105.90	391.30	9	30	17.5	F	N/A	
P2-3-4-35	9.88	1.62	15.09	25.96	206.06	16.85	262.92	437.94	9	35	17.5	F	N/A	
P2-3-4-39	8.72	1.49	17.00	28.35	237.39	24.04	282.88	239.92	9	39	17.5	F	N/A	Bed height 35 cm. Four rows over away from street.
P1-4-2-5	19.7	1.90	44.98	36.17	303.06	23.89	33.49	526.09	4	5	35	F	N/A	
P1-4-2-10	7.68	1.11	14.36	19.17	254.40	14.26	21.13	401.38	4	10	35	F	N/A	
P1-4-2-15	8.01	1.23	15.91	21.70	243.31	15.08	25.94	376.68	4	15	35	F	N/A	
P1-4-2-20	14.2	1.81	53.25	32.80	358.21	23.66	45.94	583.20	4	20	35	F	N/A	
P1-4-2-25	13.2	1.81	24.60	30.66	413.77	24.18	58.21	484.98	4	25	35	F	N/A	
P1-4-2-30	13.3	1.67	23.36	29.77	299.96	22.20	52.46	514.23	4	30	35	F	N/A	
P1-4-2-35	13.6	1.65	25.41	29.28	302.06	22.48	45.04	578.26	4	35	35	F	N/A	
P1-4-2-40	9.31	1.33	25.97	25.41	410.42	20.36	88.33	229.45	4	40	35	F	N/A	Garden #18 close to entrance. Corner of garden sampled.
P2-7-1-35	5.93	1.41	14.19	21.24	366.71	20.63	38.26	139.49	14	35	16.5	F	N/A	
P2-7-1-40	11.51	1.35	21.16	17.30	490.36	25.45	14.12	267.39	14	40	16.5	F	N/A	Next garden north from previous sample. Sampled from middle-right half of garden. Strange white layer around middle of profile.
P2-3-2-40	4.55	0.87	12.92	10.26	488.88	17.03	34.16	244.66	9	40	19	F	N/A	

P1-4-1-35	9.77	1.24	20.99	27.08	266.63	24.05	48.81	203.36	4	35	21	F	N/A	Row closest to parking lot, second from street.
P1-4-1-40	8.78	1.56	26.04	28.10	317.10	23.35	41.71	253.75	4	40	21	F	N/A	
P1-4-3-30+	10.23	1.26	21.46	26.40	306.35	26.82	62.71	217.79	4	32	26.5	F	N/A	Bed on other side of garden area across from last sample.

Revised from Gulson et al., (1995) showing potential sources and pathways lead can reach children.