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Abstract

Pilot study of a community-engaged phytoremediation garden: Evaluating site-specific efficacy of the mammoth sunflower in soil with elevated lead (Pb) in west Atlanta, GA

By Alicia May-Lin Borbón Wun

Background: Soil Pb levels above Environmental Protection Agency (EPA) screening levels (400 ppm) were recently discovered in the English Avenue neighborhood of west Atlanta. While EPA Region 4 has started excavation, members of the urban gardening organization Historic Westside Gardens (HWG) have expressed the desire for a less disruptive and affordable method for remediation. Phytoremediation, using plants to extract contaminants from soil, has been utilized in other sites of legacy contamination and was utilized for this field experiment.

Methods: Three plots were established in the native soil in an empty lot in the English Avenue neighborhood. Mammoth sunflowers were planted in two plots, one with compost and one without, while one plot was left empty. Sunflowers were planted Jun 24 and harvested Sep 21. Soil Pb was measured by X-Ray Fluorescence (XRF) and Inductively Coupled Mass Spectrometry (ICP-MS) before planting and after harvesting. The seeds of five sunflowers were tested for bioavailability of Pb and Arsenic (As). Bioavailable Pb and As levels were measured by ICP-MS following a procedure simulating human stomach and intestine digestion. A risk assessment was conducted using Integrated Exposure Uptake Biokinetic Model (IEUBK) software (EPA Superfund).

Results: Average Pb levels decreased 10 ppm ($p=0.612$) in the plot without sunflowers, decreased 22 ppm ($p=0.097$) in the plot with sunflowers without compost, and increased 143 ppm ($p<0.0001$) in the plot with sunflowers with compost. Levels of Pb and As in sunflower seeds were below FDA regulations for similar food products. The IEUBK model predicted postulated average soil Pb levels would result in 16.7% to 44.7% of the 0-72-month population to have blood Pb levels over 5 µg/dL.

Conclusions: The community-engaged model of this thesis proved highly successful in the formulation of relevant research questions to residents. Results regarding efficacy of the mammoth sunflower are inconclusive, however important logistical information can be utilized for further field experiments as interventions including the suggestion to use a plant with smaller roots given the neighborhood history of buried industrial waste. Results from a risk assessment also indicate the need for expanded blood lead level testing in children in the English Avenue neighborhood.

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Thank you to the soil that sustains us—may we treat you with more respect moving forward.

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1. Introduction

1.1 Childhood Lead Poisoning in the U.S.

While significant improvements have been made in the United States regarding reduction of lead (Pb) poisoning prevalence in children, high blood Pb levels (BLL) (>5 μg/dL) are still detected in significant segments of children in the United States. According to the National Childhood Blood Lead Surveillance Program, among programs reporting cases of elevated BLL, 3% of children less than 72 months old had a BLL >5 μg/dL. This translates to roughly 500,000 children exceeding the CDC reference level for blood lead (CDC, 2010).

Pb is a systemic toxicant, deleterious to all organ systems, but particularly toxic to the central nervous system (Sanders, Liu, Buchner, & Tchounwou, 2009)). Due to their developmental stage and high hand-to-mouth behavior, children are particularly at risk for the neurodegenerative effects of Pb poisoning. Exposure to Pb can occur through a variety of media, including soil, paint, and dust (Tchounwou, Yedjou, Patlolla, & Sutton, 2012). Recent work in New Orleans, Louisiana showed evidence of a concurrent decline in child BLL and topsoil Pb levels (Mielke et al., 2019). This decline in child BLL occurred despite concerns that unregulated reconstruction of housing in the city post-Katrina would lead to elevated BLL. Mielke et al. (2019) also found a spatial association between child BLL and topsoil lead levels. In general, urban soils in the United States tend to have higher Pb levels than suburban or rural soils, largely a function of legacy contamination from leaded gasoline, past industrial use, and the chipping of lead paint from older buildings (Filippelli, Adamic, Nichols, Shukle, & Frix, 2018; Henson, 2018).

1.2 Health Effects of Arsenic

Unlike Pb, arsenic (As) has both natural and anthropogenic sources (Teaf, 2010). Long-term exposure to inorganic As can result in As poisoning (ATSDR, 2017). As poisoning in early childhood can lead to lung disease, heart disease, kidney disease, as well as developmental delays (Teaf, 2010). Common exposure pathways are through food and water, with the main exposure route being ingestion. Given the common and growing practice of urban gardening in Atlanta, elevated concentration of As in soil could pose a threat to the health of residents who are in frequent contact with the soil. Due to the history of the area as an industrial region, there is a possibility that elevated As exist in the soil in addition to Pb given that As is associated with the smelting of ores that contain metals such as Pb (ATSDR, 2017). As was also commonly used as a wood preservative in the form of copper chromated arsenate (CCA) up until 2003, however this exposure pathway is not as well researched as through food, water, and soil (ATSDR, 2017).

1.3 English Avenue neighborhood history

English Avenue is located on the west side of Atlanta, notably adjacent to the recently constructed Mercedes-Benz stadium. In the 1950's and 60's English Avenue hosted prominent leaders of the Civil Rights movement, including Dr. Martin Luther King Jr., who lived in the nearby Vine City neighborhood (Friends of English Avenue, 2018). From the 1970's to 1990's, the neighborhood saw a drastic decrease in population, resulting in a sizeable percentage of vacant homes. As of the 2010 Census, 44% of homes in the English Avenue neighborhood were vacant. The 5-year estimates for 2013-2017 household median annual income for English Avenue was $21,881 (compared to the national five-year estimate of $57,652), and 77% of residents are Black (Census, 2017). According to 2015 data from the United States Department of Agriculture (USDA), the neighborhood was designated as an area of “Low-income census tracts where a significant number or share of residents is more than ½ mile (urban) or 10 miles (rural) from the nearest supermarket” (USDA, 2015).

These demographics are relevant to the subject matter of this study given that one response to a lack of access to affordable fresh food has been the proliferation of urban farms and gardens in English Avenue and surrounding neighborhoods. One such organization is Historic Westside Gardens (HWG). Per the HWG mission statement, their mission is to “plant urban home food gardens to cultivate community relationships and encourage equitable development in the Historic Westside neighborhoods” (Gardens, 2020).

1.4 Ongoing Community-Engaged Research Partnership

HWG and the Saikawa Lab at Emory have fostered a relationship over the past three years following the discovery of elevated Pb soil levels in several Westside Atlanta neighborhoods where levels in some areas tested higher than 2,000 ppm. For context, the Environmental Protection Agency (EPA) has an action level of 400 ppm of Pb in bare soil that is considered a “play area” (EPA, 2019). During the initial investigation of elevated Pb levels in soil, solid pieces of industrial waste, known as “slag” (see Figure 1), were brought to the attention of Dr. Eri Saikawa. Historically, neighborhoods on the west side were situated within range of several smelting sites. Long-time residents have given anecdotal evidence that use of slag to fill empty lots in the neighborhood was common practice (Miller, 2020). Among this slag, the Saikawa Lab found varying levels of heavy metal contamination, with some slag testing as high as 2,000 ppm for Pb. However, not all slag tested at these elevated Pb levels. Elevated Pb levels found in the soil is likely the outcome of a mixture of industrial waste (such as slag), lead paint, and residue from leaded gasoline.

Figure 1. Urban farmer holds pieces of slag found in her yard. Source: Georgia Health News, 2019

After EPA Region 4 was notified of elevated Pb levels in soil, a Site Investigation was initiated. Based upon early findings from the Site Investigation, EPA began excavation at sites of highest concern. Both EPA investigation and excavation are ongoing and have been met with a mixed response from neighborhood residents. While some residents have positive views on the EPA response (excavation is widely regarded as the most effective method of remediation), others are upset by the level of disruption and the removal of trees that come with excavation (Miller, 2020). Furthermore, neighborhood soil that tests below the EPA threshold of 400 ppm does not qualify for excavation by the EPA. The University of Georgia Agricultural School recommends growing crops directly in soil only if Pb levels are 75 ppm or below (Varlamoff, 2016). Given that many residents in the neighborhood partake in urban gardening (many directly into the native soil), there is an argument to be made for following a more stringent threshold in this community. Alternative methods of remediation could be instrumental in ensuring safe levels of Pb in soil, especially for those whose soil tests just below the 400 ppm threshold.

1.5 Phytoremediation as a potential community-engaged solution

Methods of Pb remediation from soil include excavation (direct removal and replacement of contaminated soil, as mentioned above) and phytoremediation (the use of plants and associated microorganisms to extract, stabilize, or degrade metals and metalloids from contaminated soil) (Chaney et al., 1997). The former is resource-intensive in terms of both equipment and cost, but also highly effective at remediating soil in a short timeframe. The latter is markedly less extractive and expensive but has only proved effective in mid-range Pb levels and can take several growing seasons to result in a reduction relevant to health outcomes (Kidd et al., 2015).

Sunflowers have been shown to be hyperaccumulators of Pb (Forte & Mutiti, 2017). Additionally, soil amendments such as compost and vermicompost have been shown to increase the amount of Pb accumulated in sunflowers (Rahman, Azirun, & Boyce, 2013; Zhi-xin, Sun, Sun, Li, & Wang, 2007). It is important to note that sunflowers are not the most effective hyperaccumulator plants for phytoextraction. However, given their tolerance of various soil types, widespread availability, and previously mentioned hyperaccumulator status, the sunflower is an ideal candidate for potential application in a neighborhood setting. Many effective alternative hyperaccumulator plants are leafy, edible plants which would not be appropriate given the setting of this study in a neighborhood where it is common to have a home garden (Vamerali, 2009). Edible plants used for phytoremediation could pose potential harm to residents.

Recently, high Pb soil levels (>2000 ppm) were found in the English Avenue and Vine City neighborhoods of Atlanta by Emory University researchers and members of the community counterpart organization HWG. Gardeners and residents have expressed a desire to take action to reduce Pb concentrations in the soil. After talks with key members of HWG, I drafted a community-based participatory field experiment to plant a sunflower garden in soil previously found to have elevated Pb levels. The execution of this field experiment was conducted collaboratively. Experimental design was crafted by myself in close consultation with urban gardeners from HWG. The urban farmer who lived near this garden took the lead on watering plants when needed and provided guidance on plant cultivation.

2. Methods

2.1 Site Description and Experimental Design

Site location was in the English Avenue neighborhood, directly adjacent to the residence of a community gardener from HWG. Soil tested near this location was previously found to have mid-range levels of Pb, averaging about 400 ppm. The site was covered with native grasses and wild peppermint prior to planting sunflowers. The site was mowed and tilled prior to planting seeds directly into native soil. Plants were watered as needed using water from the personal rain barrel of our partner community gardener.

Weeding was carried out in plots with sunflowers an average of twice per week over the growing period.

Figure 2. Phytoremediation garden. (Left) Layout of pilot phytoremediation garden. From front to back: DU1 (Sunflowers, no compost), DU2 (No sunflowers), DU3 (Sunflowers, with compost). Picture taken pre-planting. (Right) Picture of Sunflowers on Day 64 (flowers can be seen on plants in DU3, 'Sunflower (with compost)', courtesy of R. Hernandez

Three decision units (DUs) of area 42.16 cm^2 (62 cm x 68 cm) were established at the site location. DUs were set up next to one another, separated by bricks placed directly on the soil (see Figure 1). One plot had no soil amendments, and mammoth sunflowers were planted directly into the native soil (DU1, 'Sunflowers (no compost)'). One plot had no soil amendments and no sunflowers planted (DU2, 'No sunflowers'). The other plot had a compost amendment and had mammoth sunflowers planted directly into the native soil (DU3, 'Sunflowers (with compost)'). The compost was obtained from the community gardener's personal compost, sun-dried, and sieved through chicken wire. Seeds were planted on June 24, 2019, and harvest occurred on September 21, 2019 for a total of 90 days from planting to harvest.

2.2 Plant Materials

Mammoth sunflower seeds were ordered online from American Meadows (Americanmeadows.com). Sunflowers were planted in DU1 and DU3—in each plot, 13 individual holes were dug (3 inches deep), and 5 seeds were placed inside each hole.

2.3 Sampling Methods – Soil

Soil samples were taken after mowing and gently tilling the soil. Three samples were taken from each DU using an incremental method wherein each DU was partitioned into a 5 x 6 grid, and a given sample was created by taking a trowel of soil from each of the 30 smaller squares in each DU. Three soil samples from each DU were taken prior to sunflower planting as well as three samples of compost. Compost was taken from an open-air composting unit in the home garden of our partner gardener and passed through a sieve made of chicken wire into a large plastic container. Compost was sampled by mixing in container and then creating three composite samples. The container was split into 10 sections and a handful was taken from each section.

2.4 Sampling Methods – Plants

Mammoth sunflowers were grown in DU1 and DU3 for 90 days (June 24 – Sep 21). Seventeen separate stalks grew in DU1, twenty-three separate stalks grew in DU3. Each individual sunflower was assigned a letter name. All sunflowers were carefully uprooted so that as much soil was left remaining in the plot while the entirety of each plant root was extracted. Two plants from DU1 (DU1 I, DU1 G) and three plants from DU3 (DU3 B, DU3 C, DU3 T) were selected for further analysis, largely due to the presence of sunflower seeds in the flower head. Plants were selected to be a representative of the DU area, with selected plants coming from at least three different quadrants within each DU.

2.5 Lab Methods - Soil

Soil and compost samples were dried in an oven at 100°C for at least 4 hours or until dry, homogenized, passed through a 2mm sieve, and placed in plastic bags at room-temperature until analysis. Soil pH was measured for all pre-planting soil samples using a pH probe (Cole-Parmer P200-02 Benchtop pH Meter). Pb levels in soil were enumerated through X-Ray Fluorescence analyzer (Thermo Scientific™ Niton XL3t GOLDD+ XRF Analyzer). For each pre and post sample, 4 replicate measurements were taken, the average of which was used to represent Pb levels for a given sample. Each DU had 3 pre-planting soil samples and 3 post-harvest samples. DU3 also had a compost sample but only pre and not post. Post-planting soil samples for DU3 included compost mixed on top during initial planting.

The content of heavy metals in soil were also determined by Inductively Coupled Mass Spectrometry (ICP-MS), following an acid digestion in Millipore water, nitric acid (HNO_3), and hydrogen peroxide (H_2O_2). Soil samples were mixed with Millipore water and HNO_3 and heated to 100°C for one hour, followed by two rounds of HNO_3 digestion at 100°C, and finally one hour of digestion in Millipore water and H_2O_2 at 100°C. Following a centrifuge at 400 rpm for 10 minutes, the supernatant samples were evaluated for heavy metal content by ICP-MS.

2.6 Lab Methods – Seeds

Plants were air-dried for 2 weeks, and further dried in an oven at 70°C if necessary. Dry mass of the plants was taken prior to crushing, and again after crushing. Plants were cut and separated into roots, stems, leaves, seeds, and flower heads. Plants were crushed into a powder and stored in plastic bags at room temperature until analysis. Only the seeds were analyzed at the time of this paper.

Bioavailability of Pb in sunflower seeds (the only edible portion of the sunflower) was determined via ICP-MS following a digestion through a simulated stomach and then intestine. Sunflower seed samples were mixed with pepsin and Millipore water at a pH of 2.5 at 37°C for one hour, simulating stomach digestion. Half of the stomach-digested sample was removed, and the other half was brought to a pH of 7 and digested in pancreatin and bile salts for one hour to simulate intestinal digestion. Following a centrifuge at 400 rpm for 10 minutes, the supernatant of the stomach-digested, and stomach + intestine-digested samples were evaluated for heavy metal content by ICP-MS.

2.7 Statistical Analysis

Pre and post Pb levels were statistically analyzed using a paired Student's t-test. There were only an adequate number of Pb (XRF) samples for statistical testing. Due to a low sample size (n=3) As measurements in soil were not appropriate to be tested through a paired student's t-test. Hypotheses for these statistical tests were two-tailed, to allow for the possibility that a plot showed either an increase or decrease in Pb. XRF and ICP-MS Pb measurements were examined for correlation. All statistical analyses were conducted in R version 3.6.2.

2.8 Population Risk Assessment

The Integrated Exposure Uptake Biokinetic Model (IEUBK) for Pb in Children was downloaded from the EPA Superfund website (EPA, 2009). The "Beginner Wizard" Setting was utilized. Default values were used for the following parameters: Soil/Indoor Dust Concentration (µg/g), Amount of Soil/Dust Ingested Daily (g/day), Outdoor Air Pb Concentration (µg/m^3), Time Spent Outdoors (hrs/day), Ventilation Rate (m^3/day), Lung Absorption (%), Dietary Lead Intake (µg/day), Water Consumption (L/day), Lead Concentration in Drinking Water (µg/L), Absorption Fraction Percent. The model is based on four components—exposure, uptake, biokinetic properties, and probability distribution. A full explanation of this model can be found in the *Technical Support Document for the Integrated Exposure Uptake Biokinetic Model for Lead in Children (v0.99d) [NTIS #PB94-963505, EPA 9285.7-22] (December 1994)* (Choudhury, 1994).

Based on the default parameters and a manually input "Outdoor Soil Lead Concentration," the percentage of the 0-72-month-old population expected to have a BLL > 5 µg/dL was given by each model. Values for 'Outdoor Soil Lead Concentration' were selected based on the average of all 'Pre' Pb values of each plot measured by XRF (300 ppm), the average of all 'Pre' Pb values of each plot measured by ICP-MS (233 ppm), and the 'Pre' Pb values of Compost measured by ICP-MS (173 ppm). Values for Compost measured by XRF were not included as a separate input value because average XRF Pb levels (168 ppm) were nearly identical to average ICP-MS Pb levels (173 ppm). The UGA direct-plant standard (75 ppm) and the EPA bare residential, play area soil standard (400 ppm) were used to provide a comparison to measured values.

3. Results

3.1 Change in Soil Pb

The change in soil Pb levels post-planting of sunflowers varied for each plot (Table 1). Pb levels were measured both by XRF and ICP-MS. Both measurements are shown for each plot as ‘No Sunflowers’, ‘Sunflowers (no compost)’, ‘Sunflowers (with compost)’. Three boxplots are shown for the ‘Sunflowers (no compost)’ plot, with only a ‘Pre’ reading for compost since it was not feasible to sort out the compost after harvesting the sunflowers.

Average soil Pb levels in the ‘No sunflower’ plot increased 10 ppm by XRF measurements (n=12)—this increase was not statistically significant (p=0.612, Table 2). Average soil Pb levels increased in this same plot by 18 ppm by ICP-MS measurements (n=3) (Figure 3). Average Pb soil levels in the ‘Sunflower (no compost)’ plot decreased by 22 ppm by XRF measurements, which was not statistically significant (p=0.097, Table 2). Average soil Pb levels in this plot decreased 21 ppm by ICP-MS measurements (n=3) (Figure 4). Average soil Pb levels in the ‘Sunflower (with compost)’ plot increased 143 ppm by XRF measurements (n=12)—this increase was statistically significant ($p<0.0001$, Table 2). Average soil Pb levels increased in this same plot by 65 ppm by ICP-MS measurements (n=3) (Figure 5).

Table 1. Paired Samples Statistics, Pb levels measured by XRF and ICP-MS

		XRF			*ICP-MS*		
	Pre or Post	*Mean (ppm)*	*N*	*Std. Deviation*	*Mean (ppm)*	*N*	*Std. Deviation*
No sunflower	Pre	365	12	81.9	246	3	89.0
	Post	375	12	34.2	264	3	59.7
Sunflowers (no compost)	Pre	107	12	28.3	69.2	3	21.1
	Post	85	12	14.5	48.4	3	11.8
Sunflowers (with compost)	Pre	555	12	38.7	442	3	10.4
	Post	698	12	48.5	508	3	40.1
Compost	Pre	168	12	46.4	174	3	11.2

Table 2. Results of paired t-test for change in Lead (Pb) levels in each plot (Pre-Post), measured by XRF

	Mean of the difference	*95% Confidence Interval of the Difference*		*t*	*df*	*P(T<=t) two-tail*
		Lower	*Upper*			
No sunflowers	-10	-52.7	32.7	-0.515	11	0.617
Sunflowers (no compost)	21.7	-4.62	47.9	1.814	11	0.0970
Sunflowers (with compost)	-143	-184.7	-100.6	-7.471	11	<0.0001

Table 3. pH of soil and compost prior to planting and harvest of sunflowers. Note that the soil from the 'Sunflowers (with compost)' soil sample does not have compost, rather this is the native soil from the plot where 'Sunflowers (with compost)' was located.

Plot	*Pre-pH*	*N*	*Std. Dev*
No sunflowers	7.36	3	0.172
Sunflowers (no compost)	7.55	3	0.274
Sunflowers (with compost)	7.56	3	0.271
Compost	6.60	3	0.046

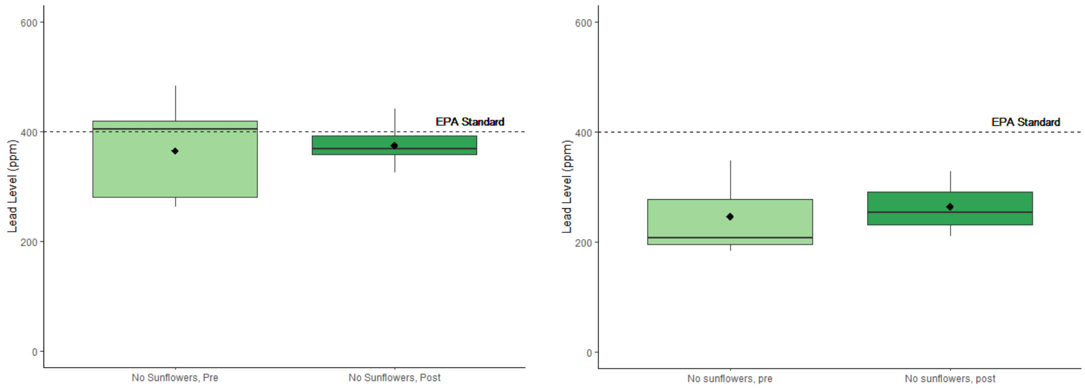

Figure 3. Change in Lead (Pb) Levels in Soil from 'No sunflowers' plot. Boxplot on the left shows measurements taken by X-Ray Fluorescence (XRF); boxplot on the right shows measurements taken by ICP-MS. Light green boxplots represent 'Pre' readings, while dark green boxplots represent 'Post' readings.

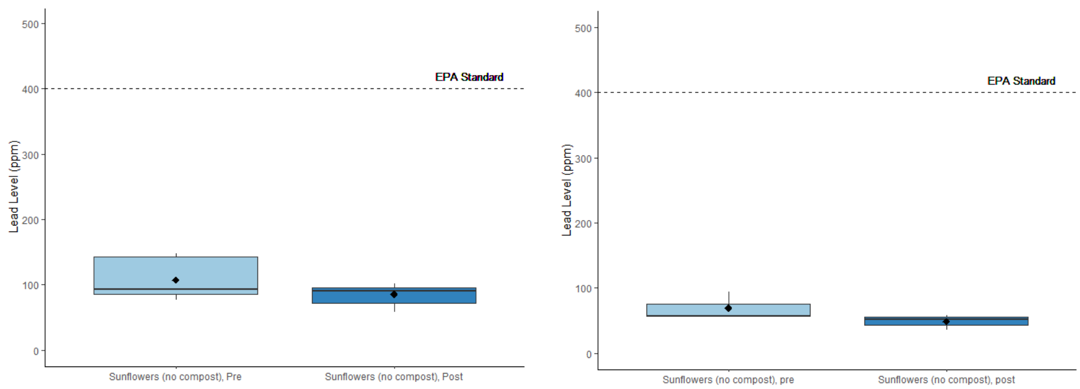

Figure 4. Change in Lead (Pb) Levels in Soil from 'Sunflowers (no compost) plot. Boxplot on the left shows measurements taken by X-Ray Fluorescence (XRF); boxplot on the right shows measurements taken by ICP-MS. Light blue boxplots represent 'Pre' readings, while dark blue boxplots represent 'Post' readings.

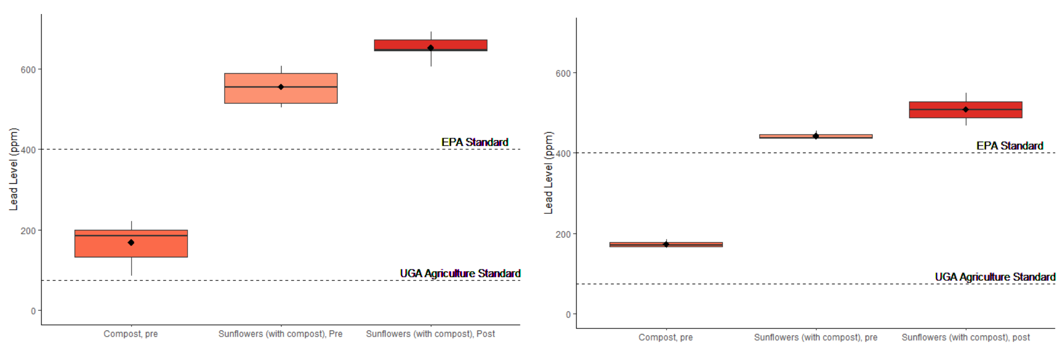

Figure 5. Change in Lead (Pb) Levels in Soil from 'Sunflowers (with compost) plot. Boxplot on the left shows measurements taken by X-Ray Fluorescence (XRF); boxplot on the right shows measurements taken by ICP-MS. Leftmost boxplot (red-orange) shows levels for compost. Middle boxplots (light red) represent 'Pre' readings, while dark red boxplots represent 'Post' readings.

3.2 Change in Soil As

As levels in soil showed similar trends as Pb levels (Table 4). In every plot, Pb and As either both increased or both decreased. The plot with 'No sunflowers' showed an increase in As of 0.16 ppm (Figure 6). The 'Sunflowers (no compost)' plot showed a decrease of 0.45 ppm (Figure 7). The 'Sunflowers (with compost)' plot showed an increase of 0.63 ppm (Figure 8). All samples tested below the EPA screening level of 35 ppm (Teaf, 2010).

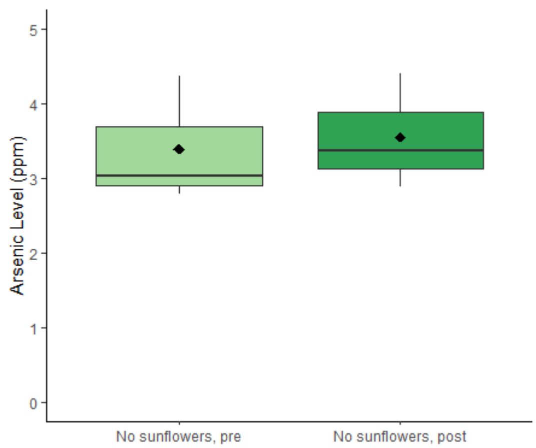

Figure 6. Change in Arsenic (As) Levels in Soil from 'No sunflowers' plot. The light green box represents 'Pre' levels, and the dark green box represents 'Post' levels.

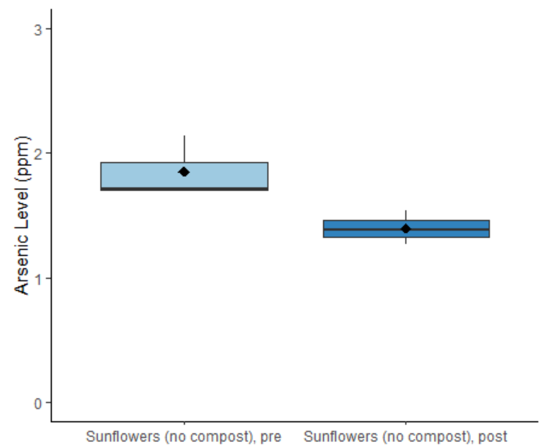

Figure 7. Change in Arsenic (As) Levels in Soil from 'Sunflowers (no compost) plot. The light blue box represents 'Pre' levels, and the dark blue box represents 'Post' levels.

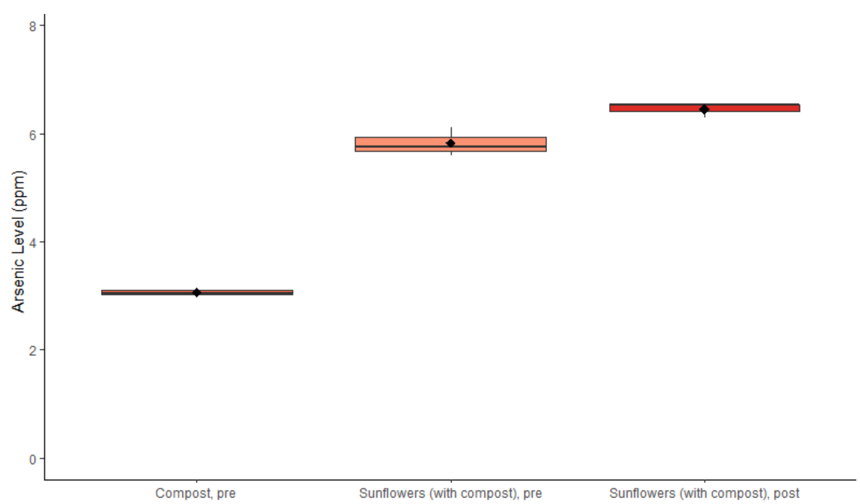

Figure 8. Change in Arsenic (As) Levels in Soil from 'Sunflowers (with compost) plot. The light red box represents 'Pre' levels, and the dark red box represents 'Post' levels.

Table 4. Paired Samples Statistics, As levels measured by ICP-MS

	Pre/Post	*Mean*	*N*	*Std. Dev.*
No sunflower	Pre	3.39	3	0.849
	Post	3.55	3	0.773
Sunflowers (no compost)	Pre	1.85	3	0.251
	Post	1.40	3	0.136
Sunflowers (with compost)	Pre	5.82	3	0.271
	Post	6.45	3	0.136
Compost	Pre	3.06	3	0.081

3.3 Correlation of XRF and ICP-MS Measurements

Pb levels measured by XRF and by ICP-MS fell along a regression line with a slope of 0.7434 ppm (ICP-MS)/ppm (XRF) and an R^2 value of 0.9766 (see Figure 9). Pb levels measured by ICP-MS were lower than all corresponding XRF measurements for all plots except Compost (see Table 6).

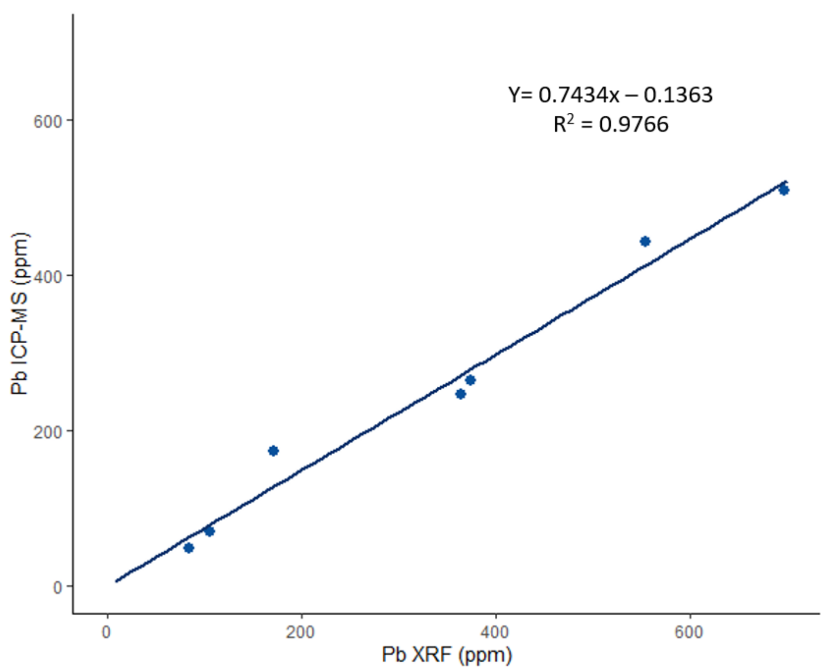

Figure 9. Correlation of Pb measurements in soil for two different methods. Values measured by XRF on x-axis, values measured by ICP-MS on y-axis.

Table 5. Average Pb Levels measured for each plot by XRF and ICP-MS.

	Pre or Post	*Mean Pb (XRF)*	*Mean Pb (ICP-MS)*	*Difference in Measurement (ppm)*
No sunflowers	Pre	365	245.77	119.06
	Post	375	263.73	111.1
Sunflowers (no compost)	Pre	107	69.21	37.71
	Post	85	48.40	36.85
Sunflowers (with compost)	Pre	555	442.30	112.53
	Post	698	507.76	189.74
Compost	Pre	172	173.56	1.28

3.4 Bioavailability Results in Sunflower Seeds

Seeds from two sunflowers grown in the ‘Sunflowers (no compost)’ plot and three sunflowers grown in the ‘Sunflowers (with compost)’ plot were tested for bioavailability of Pb and As after a stomach and intestine digestion. Post-stomach Pb measurements were available for one out of five seed samples, and post-intestine Pb measurements were available for three out of five seed samples (Table 6).

Table 6. Level of bioaccumulation of Pb in sunflower seeds grown in contaminated soil. All sunflower seeds tested below the FDA allowable level of Pb. Levels of Pb are higher in sunflowers that grew in soil with higher Pb initial Pb levels. Some samples were not readable and are represented with an “N/A” in this table. Soil Pb level reported is level determined by ICP-MS.

Plot Type	*Plant Sample (n=1)*	*Pre-Pb Levels in Soil of Plot (ppm)*	*Pb Post-Stomach (ppb)*	*Pb Post-Intestine (ppb)*	*FDA maximum allowable Pb level in candy (ppm)*
No compost	DU1 I	69.2	N/A	0.0320	0.10
No compost	DU1 G	69.2	N/A	2.85E-03	0.10
With compost	DU3 B	442	N/A	1.50	0.10
With compost	DU3 C	442	1.33	N/A	0.10

Post-stomach As measurements were viable for two out of five seed samples, and post-intestine As measurements were viable for all seed samples (Table 7). All levels of Pb measured in seeds were below the U.S. Federal Drug Administration (FDA, 2006) maximum allowable level of Pb in candy likely to be consumed by children. All levels of As measured in seeds were below the FDA maximum allowable level of As in infant rice cereal (FDA, 2016). No FDA Pb or As maximum allowable levels were available for sunflower seeds, specifically. FDA levels utilized for comparison were selected due to their basis on childhood consumption (candy for Pb, and infant rice cereal for As).

Table 7. Level of bioaccumulation of As in sunflower seeds grown in contaminated soil. All sunflower seeds tested below the FDA allowable level of As. Levels of As are higher in sunflowers that grew in soil with higher As initial As levels. Some samples were not readable and are represented with an "N/A" in this table. Soil As level reported is level determined by ICP-MS.

Plot Type	*Plant Sample (n=1)*	*Pre-As Levels in Soil of Plot (ppm)*	*Pb Post-Stomach (ppt)*	*Pb Post-Intestine (ppb)*	*FDA maximum allowable As level in infant rice cereal (ppm)*
No compost	DU1 I	1.85	N/A	0.619	0.10
No compost	DU1 G	1.85	N/A	0.638	0.10
With compost	DU3 B	5.82	71.6	1.54	0.10
With compost	DU3 C	5.82	N/A	0.944	0.10
With compost	DU3 T	5.82	44.9	0.141	0.10

While sample size is too small to conduct statistical testing, observational evidence shows a relationship between Pb soil levels and Pb accumulated in seeds. Seeds grown in soil that measured 442.3 ppm Pb accumulated 1.50 ppb Pb, while seeds grown in 69.2 ppm Pb soil accumulated 0.160 ppb Pb on average (Table 6). A similar, if less pronounced trend is seen with As levels in soil and seeds. Seeds grown in soil with As levels of 5.82 ppm accumulated a post-intestine level of 0.875 ppb on average, while seeds grown in soil with an As level of 1.85 ppm accumulated a post-intestine level of 0.629 ppb on average (Table 7).

3.5 Population Risk Calculation

IEUBK Software (EPA) was used to estimate the population proportion of children 0-72 months expected to have a BLL greater than or equal to 5 ug/dL, which is the CDC Blood Lead Reference Value (BLRV). The BLRV was calculated based on the 2007-2008 and 2009-2010 National Health and Nutrition Examination Survey (NHANES) blood lead distribution in children (CDC, 2010). The value of 5 ug/dL represents the 97.5th percentile. However, it is worth noting that CDC states that "there is no safe level of BLL" (CDC, 2010). Values for 'Outdoor Soil Lead Concentration' were selected based on the UGA direct-planting standard, the average 'Post' values of each plot measured by XRF and ICP-MS, the 'Pre' value for compost measured by XRF, and the EPA screening level for bare soil.

Given the 'Outdoor Soil Lead Concentration' of 75 ppm, 173ppm, 233 ppm, 300 ppm, and 400 ppm, the estimated percentage of the 0-72 month population to have a BLL > 5 µg/dL is 0.854, 8.26, 16.7, 27.9, 44.7, respectively. Values from Fulton County were calculated from the Georgia Childhood Lead Poisoning Prevention Program Database (GCLPPP) for comparison (Georgia Department of Public Health, 2018).

Table 8. Results from IEUBK Model. Model gives predicted % of population that will have a BLL above a certain cutoff, for a specified age range, given a soil Pb value. UGA agricultural standard = 75ppm; Pb level in compost= 173 ppm; average of pre-Pb (ICP-MS) =233 ppm; average of pre-Pb (XRF) =300 ppm; EPA soil screening level= 400ppm

Lead Soil Parameter (ppm)	*Lead Water Parameter (ppm)*	*% of Population 0-72 expected to have BLL > 5 µg/dL*	*% of children tested from Fulton county with BLL > 5 µg/dL (2018)*
75	4	0.854	1.75
173	4	8.26	1.75
233	4	16.7	1.75
300	4	27.9	1.75
400	4	44.7	1.75

4. Discussion

4.1 Efficacy of mammoth Sunflowers

Results from the two Sunflower plots are inconclusive. The control plot seems to indicate that there were not significant external sources of Pb during the growing period, such as wastewater runoff or resuspended lead dust from development. This supports the assumption that the Pb in soil is a legacy contaminant from either past industry, leaded gasoline, or chipping paint. Recent work by Henson et al. (2018) investigating elemental concentrations of soil in the Atlanta urban environment indicated that Pb levels in soil are driven by anthropogenic sources rather than a natural wearing of the bedrock in the Georgia Piedmont.

Figure 10. Roots of Sunflower from 'Sunflowers (no compost)' during harvest. Researchers had to dig approximately 8 inches deep into the soil to retrieve the plant.

One possible reason for the increase in Pb concentrations in the 'Sunflowers (with compost)' Plot is due to the depth to which soil had to be dug for plants to be removed (Figure 10). Assuming that a major source of Pb in this soil is the accumulation of slag used as filler for empty lots, it is logical to conclude that the deeper one digs, the closer to reservoirs of slag one gets. The reason that this same trend was not seen in the 'Sunflower (no compost)' plot could be due to lower Pb levels pre-planting compared to the 'Sunflower (with compost)' plot. A potential justifiable argument could be that slag or other Pb-containing waste were buried more in the wooded area towards the area of the lot away from the street (Figure 11).

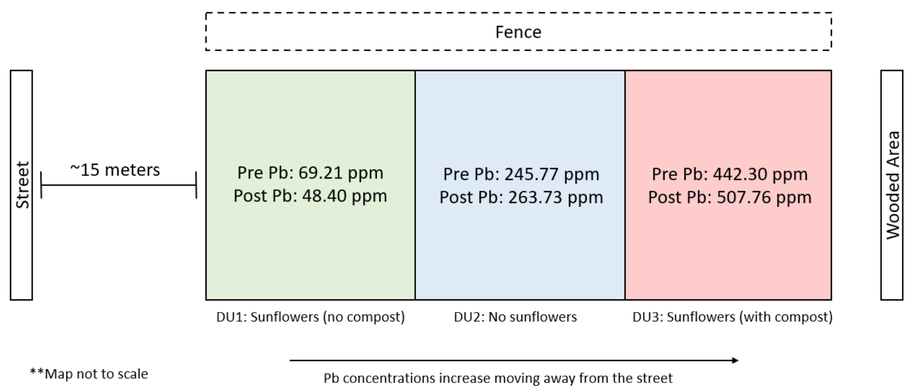

Figure 11. Pre and post Pb values in plots increase moving away from the street and towards the wooded area. Pb values shown were measured by ICP-MS.

There is also a possibility that the compost altered the ability of the sunflowers to extract Pb from the soil. However, this would run contrary to expectations set by previous literature given that compost had an average pH of 6.60, lower than any of the native soil sampled (which ranged from 7.36-7.56). This lower pH would make the soil *more* acidic, a property that generally increases the mobility of Pb (Rahman et al., 2013)

4.2 Inter-Measurement Correlation: XRF vs. ICP-MS

Pb levels in the same samples were measured by XRF and ICP-MS. ICP-MS is regarded as the more accurate measurement method but is more time and resource-intensive than XRF. The slope of the regression line (0.743) indicates a moderate level of agreement between XRF and ICP-MS measurements. Past work on the agreement of Pb levels measured through these two methods had slopes much closer to 1 ((Henson, 2018). This discrepancy is likely due to the small sample size (n=7) used to compare the two enumeration methods.

While the sample size for comparing these two methods was relatively small, another notable aspect of these results is that Pb levels measured through XRF were consistently higher than through ICP-MS (Table 5). For soil samples >200 ppm (excluding Compost), the XRF measurements were on average 133 ppm greater than ICP-MS measurements for the same samples. For the soil samples <200 ppm (excluding Compost) measurements differed by an average of 37.28 ppm. Compost readings were nearly identical (difference of 1.29 ppm). These discrepancies seem to imply that XRF readings could potentially overestimate the true values of Pb in soil. This would likely serve as a protective measure for public health. However, the composition of soil is highly heterogenous and there is the potential that Pb levels truly varied by the degree expressed.

4.3 Accumulation of Pb and As in Sunflower Seeds

Bioavailability of Pb and As in sunflower seeds harvested from sunflowers grown in contaminated soil was an expressed concern by urban farmers in this neighborhood.

Results from viable data indicate that no Pb or As levels exceeded FDA maximum allowable levels for comparable foods.

While sample size is too small to conduct statistical testing, observational evidence shows a moderate relationship between Pb soil levels and Pb accumulated in seeds, and a weaker relationship between As soil levels and As levels in seeds. Similar community-based work in contaminated soil found a significant linear correlation with amount of As that accumulated in edible portions of plants with soil As concentration (Ramirez-Andreotta, Brusseau, Artiola, & Maier, 2013). These results suggest that Pb and As translocated the entire length of the sunflower into the seeds. Further analysis of the roots, stems, leaves, and flower of the plants would give a better idea of Pb and As movement.

4.4 Population Risk

Projected proportions of the 0-72 month population with a BLL > 5 ug/dL were much higher than current figures available through the GCLPPP. These discrepancies are likely due to a combination of soil heterogeneity, the population of children tested in GCLPPP, and multiple exposure pathways for lead.

The Pb levels selected for the "Outdoor Soil Lead Concentration" were based upon the UGA upper threshold for direct planting, average Compost Pb levels, the average pre-harvest soil Pb levels measured by ICP-MS, the average pre-harvest soil Pb levels measured by XRF, and the EPA play area screening level. It is unclear how representative these levels are for the entirety of the English Avenue neighborhood, given how heterogenous Pb levels in urban soil can be. In the study area alone, *Pb levels* *ranged from below to above the EPA screening level* of 400 ppm (85-679 ppm). In conjunction with past research in this neighborhood, this study suggests *average* Pb levels in the native soil would likely fall between 233 ppm (the average Pb level of all three plots) and 400 ppm (the EPA screening level). According to the IEUBK model, these levels would result in 16.7% to 44.7% of the 0-72-month population to have blood Pb levels over 5 µg/dL. Measured BLL in Fulton County fall far below these estimates, with only 1.75% of children tested showing BLL > 5 µg/dL. This discrepancy indicates a need for more widespread BLL testing within the specific neighborhoods of English Avenue and adjacent Vine City. Another potential explanation for this discrepancy could be an overweighting of the importance of soil as an exposure pathway within the IEUBK model. However, recent work by Mielke et al. (2019) suggests a relationship between topsoil Pb levels and children's BLL. It is also worth noting that while the estimated *average* of soil Pb would fall between 233-400 pm, there is evidence of areas in the neighborhood with exceptionally high soil Pb levels, making individual risk to a child more difficult to generalize from average values.

4.5 Community-Engaged Approach

This field experiment employed the unique element of a community-engaged approach. Decision-making was collaborative on site location, plant selection, and distribution of labor. Laboratory methods were informed by past scientific literature and were communicated to our community partner, but not necessarily informed by the opinions of HWG. Key research questions were prioritized based upon community concern and scientific validity. A main driver of bioavailability testing for sunflower seeds was an expressed interest from multiple members of the community. Sunflowers attracted pollinators, provided a positive aesthetic for the neighborhood block, and served as an important tool for community building between Emory researchers and neighborhood residents. Regular maintenance of the garden allowed for consistent dialogue around Pb in the soil with our main community partner, as well as other residents who would stop to look at the sunflowers. This field experiment was also complemented by outreach efforts in the surrounding neighborhood to raise awareness about blood Pb testing, as well as immediate steps to reduce exposure to potentially contaminated soil. Exposure reduction methods suggested can be seen outlined in the flyer in Appendix A.

5. Conclusions

5.1 Suggestions for Future Use of Phytoremediation

While the efficacy of mammoth sunflowers in native soil is hard to determine based upon this data, the experimental logistics offer guidance for future experiments. Given the possibility that slag is buried beneath layers of soil, a hyperaccumulator with a smaller root system may prove equally effective and pose lower risk. Another smaller strain of *Helianthus annus* would be an appropriate plant to use for a similar iteration of this experiment. While other hyperaccumulator species are more effective then *Helianthus annus* there is an added risk that someone might consume the plant and any heavy metals the plant has accumulated. During harvesting, a plant with a smaller roots system would reduce the likelihood that gardeners would be required to dig up soil with potentially dangerous levels of heavy metal contamination. Another suggestion would be to thin flowers to be evenly distributed across the soil plot around day twenty. At this time in their growth, the flowers would have root systems large enough to be re-planted, but not so large that they would require deep digging in the soil and potential unearthing of more contaminated soil. The even distribution of plants in soil would allow roots to grow unencumbered by other remediation plants as well as allow for a more uniform extraction of heavy metals from soil.

Another big question that remains is that of disposal. Pb and As levels in the sunflowers grown in this experiment still remain to be analyzed. While a range of disposal options have been investigated for soil contaminated with heavy metals (e.g. incineration, compaction), the most feasible option is compost (Kovacs & Szemmelveisz, 2017). Plants grown for phytoextraction could be composted and then mixed with other non-contaminated compost material in order to reduce the overall concentration of Pb in the soil. This process would necessitate strict oversight and management by a community member who would remain in the neighborhood for the duration of time it would take the plants to break down. Again, further analysis of the concentration of Pb in the plants used for phytoextraction in the experiment will help inform disposal.

5.2 Suggestions for Continued Relationship of Lab Group with Community

Given the inconclusive results on phytoremediation, next steps in this community should focus on the reduction of Pb exposure and increased blood Pb testing in children. However, the pursuit of community-level solutions that reduce Pb concentration in soil should not be abandoned altogether. Using the lessons from this experiment, a plan moving forward should be crafted in collaboration with HWG. Soil testing by the

Saikawa Lab should also continue, given the continued interest by residents. Pb values obtained from further soil testing can be used to inform an estimate for the average outdoor Pb levels in this neighborhood.

Research should also be pursued regarding the potential impacts of redevelopment in areas with contaminated soil. Given the hypothesis that industrial slag was used as “filler” for decades, the unearthing of soil that is often necessary for construction could pose a health hazard for residents in the surrounding areas.

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Appendix A

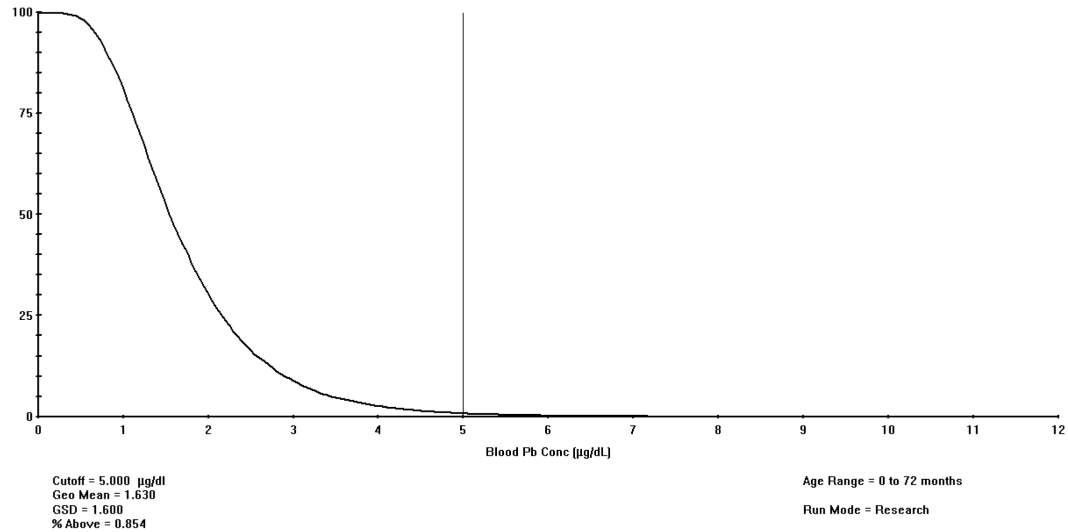

Figure 12. Probability distribution of expected proportion of population (0-72 months) to test for BLL above 5 ug/dL, given the soil Pb concentration of 75 ppm (UGA low risk limit). The percent of the 0-72 month old population with BLL > 5 ug/dL is estimated to be 0.854%.

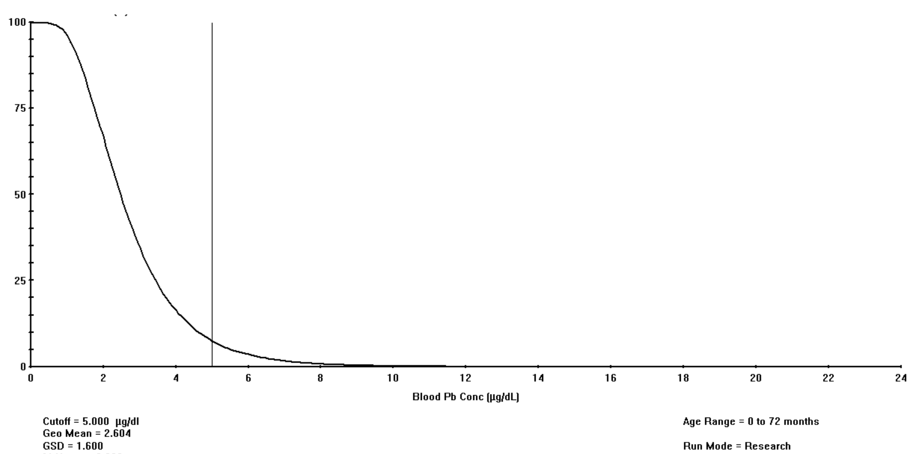

Figure 13. Probability distribution of expected proportion of population (0-72 months) to test for BLL above 5 ug/dL, given the soil Pb concentration of 173 ppm (the amount of Pb in compost). The percent of the 0-72 month old population with BLL > 5 ug/dL is estimated to be 8.26%.

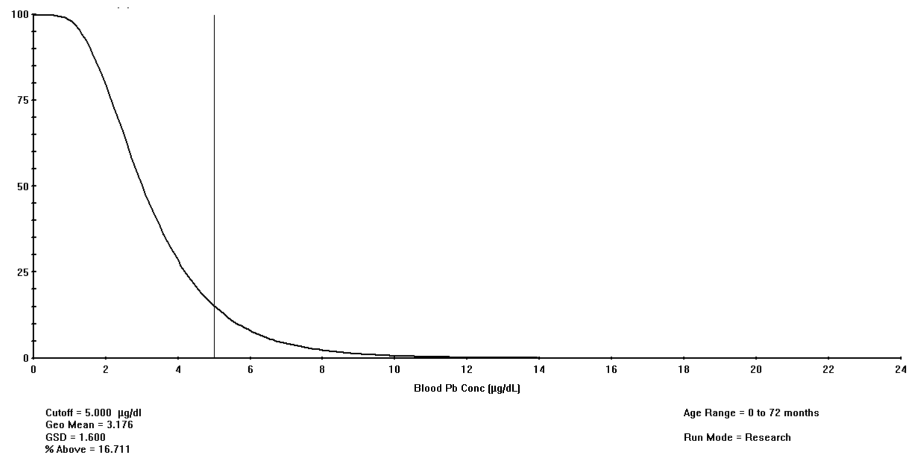

Figure 14. Probability distribution of expected proportion of population (0-72 months) to test for BLL above 5 ug/dL, given the soil Pb concentration of 233 ppm (average of all pre-Pb level measured by ICP-MS). The percent of the 0-72 month old population with BLL > 5 ug/dL is estimated to be 16.7%.

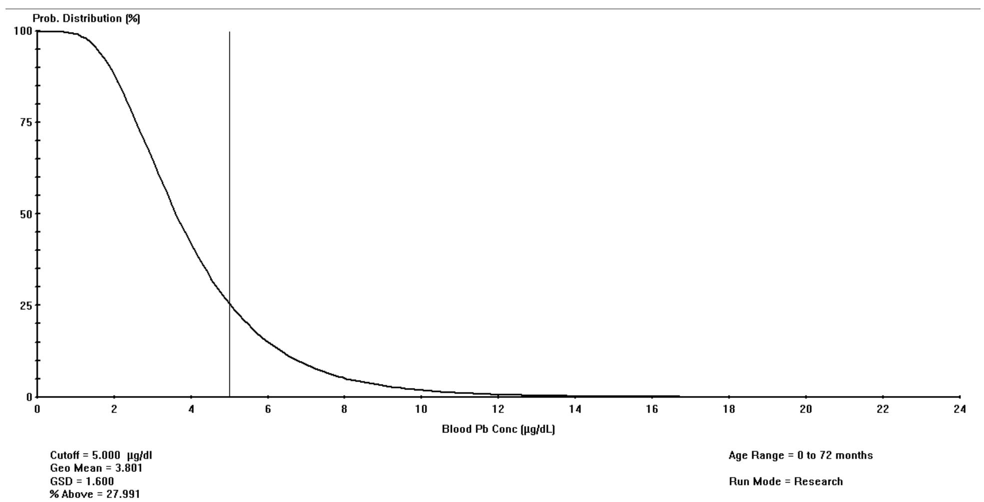

Figure 15. Probability distribution of expected proportion of population (0-72 months) to test for BLL above 5 ug/dL, given the soil Pb concentration of 300 ppm (average of all pre-Pb levels measured by XRF) The percent of the 0-72 month old population with BLL > 5 ug/dL is estimated to be 28.0%.

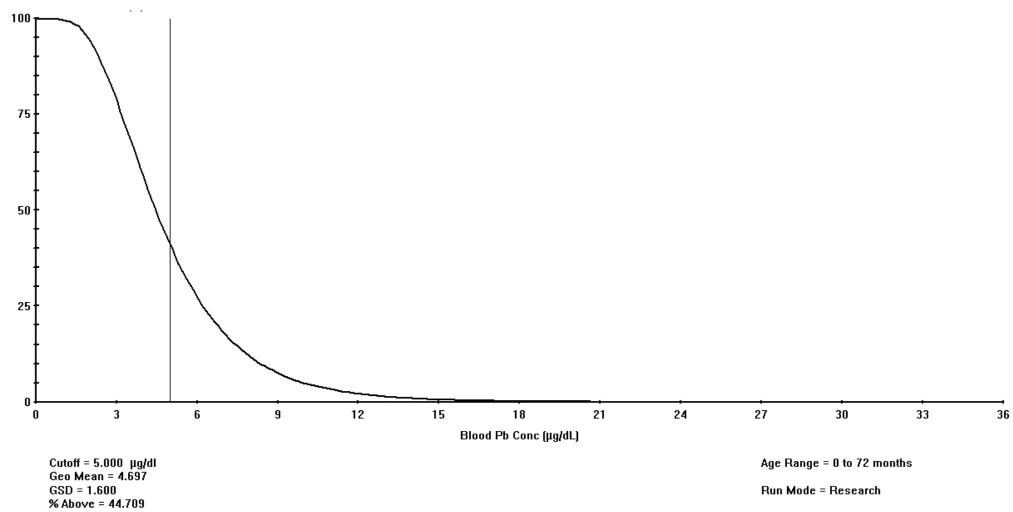

Figure 16. Probability distribution of expected proportion of population (0-72 months) to test for BLL above 5 ug/dL, given the soil Pb concentration of 400 ppm (EPA screening level). The percent of the 0-72 month old population with BLL > 5 ug/dL is estimated to be 44.7%.

Figure 17. Flyer created for community engagement to decrease exposure to contaminated soil.