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Puerto Rico Urban Garden Soils and Plants Study Summary

United States Environmental Protection Agency's (USEPA) Region 2 shipped soil and plant samples collected at or near urban garden locations in San Juan, Puerto Rico. Soils and plants from the urban garden areas were sent to USEPA's Office of Research and Development (ORD) for total arsenic and lead concentrations and bioaccessibility testing for these inorganics, which was conducted in Karen Bradham's lab (ORD, Research Triangle Park, North Carolina). After collecting weights for the soil containers and contents, the soils were blended and spread out in drying trays. The trays containing the soil were placed in an air-drying oven and dried for ~ 5 days at < 40 ºCelsius and sample weights were collected subsequent to air-drying. The soil was then added to a vibrating 2 millimeter stainless steel sieve screen to remove any large chunks of aggregated soil. Material remaining on the screen was disaggregated using a gloved hand and rescreened. The soil was sieved to < 250 micrometers to maximize the quantity of soil for bioaccessibility and total lead and arsenic analysis. The soil was passed through a riffler five times and aliquots were collected in pre-cleaned 250 milliliter high-density polyethylene bottles. The soil samples were extracted according to EPA Method 9200.2-86 *Standard Operating Procedure for an In Vitro Bioaccessibility Assay for Lead in Soil* dated April 2012 with the following exceptions: duplicate extractions of each soil sample were conducted (duplicate samples are only required once per batch according to EPA Method 9200.2-86) and arsenic values are reported (method is in the process of being validated for arsenic by the EPA Technical Review Workgroup Bioavailability Committee). The plant samples were homogenized and freeze dried to collect dry weights. Microwave assisted digestion of the plant and soil samples was completed using USEPA Method 3052 and 3051A, respectively. Lead and arsenic analysis in the sample digests was completed by USEPA Method 6010C (Inductively Coupled Plasma-Optical Emission Spectroscopy). All microwave assisted digestion and analysis qualtiy controls (QCs) were within acceptable quality assurance parameters as described in USEPA Solid Waste methods guidelines.

Site Descriptions

Soils and plants were taken from three urban garden sites, labeled Site 1, 2 and 3. Figure 1 below shows the area around the Martin Peña Special Planning District (as designated by the Puerto Rico Planning Board) in San Juan, Puerto Rico, which is where the three urban gardens are located. Some of these

community vegetable gardens are the result of the efforts of empowered citizens who organized their communities, cleaned up a parcel of land, and created a vegetable garden. Another of these gardens were created in vacant lots that arose as result of housing demolitions and further relocations being undertaking in the area. The district of interest (highlighted in yellow) is shown more closely in Figure 2. The exact locations are not disclosed to preserve anonymity of these communities. As can be seen, the area is urbanized, with a canal splitting the district.

Figure 1: Satellite Image of the area surrounding the Martin Peña District in San Juan, Puerto Rico.

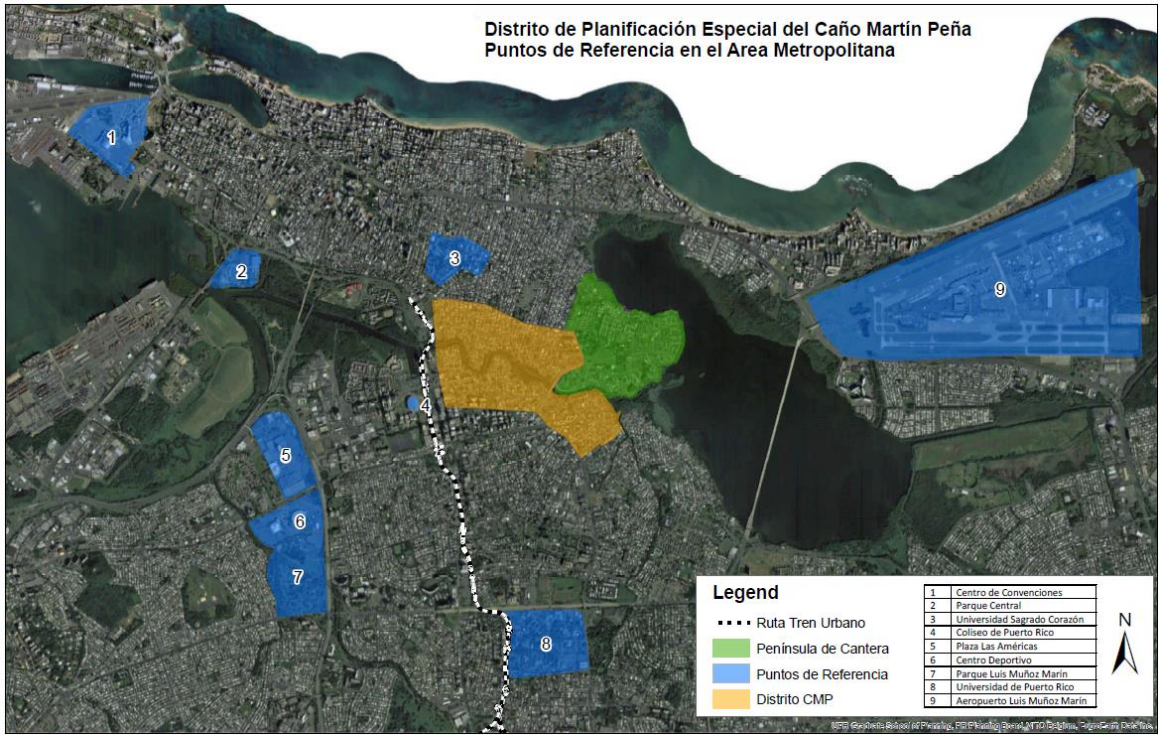
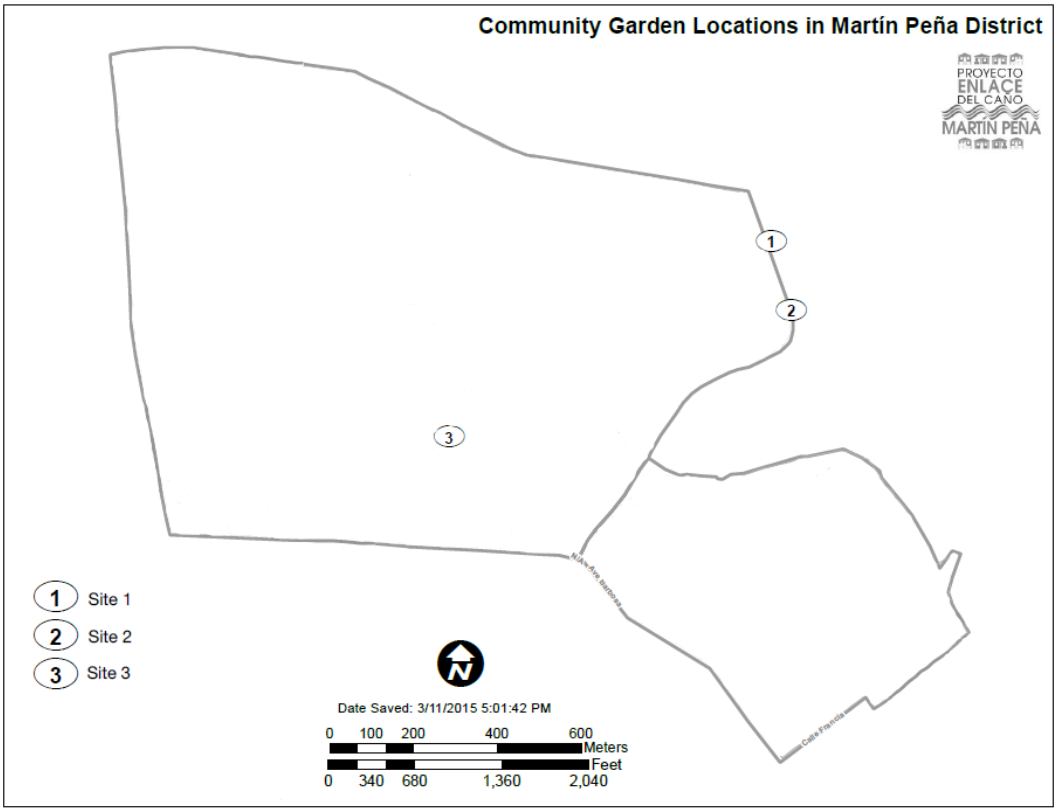


Figure 2: A closer look at the proximity of the urban garden sites, as highlighted in yellow in Figure 1.



Total soil and plant lead and arsenic concentrations

Total arsenic and lead concentrations in soils sampled across the conterminous United States of America range from 0.1-55 and 2-300 milligrams per kilogram (mg/kg or parts per million), respectively (Adriano, 2001). We are currently conducting a literature review for soil and plant concentrations reported in Puerto Rico. General plant concentrations within the conterminous USA for lead range from 0.7-7.2 mg/kg in background soils and 2.5-82 mg/kg in soils containing 200 mg/kg total lead. General plant concentrations within the conterminous USA for arsenic range from 0.1-1000 mg/kg (high concentrations found in rice and rice roots).

Ecological Soil Screening Levels (Eco-SSLs) are concentrations of contaminants in soil that are protective of ecological receptors that commonly come into contact with and/or consume biota that live in or on soil. Eco-SSLs are derived separately for four groups of ecological receptors: plants, soil invertebrates, birds, and mammals. As such, these values are presumed to provide adequate protection of terrestrial ecosystems. Eco-SSLs are derived to be protective of the conservative end of the exposure and effects

species distribution, and are intended to be applied at the screening stage of an ecological risk assessment. The Eco-SSLs are not designed to be used as cleanup levels and the USEPA emphasizes that it would be inappropriate to adopt or modify the intended use of these Eco-SSLs as national cleanup standards. The Eco-SSL for plants for As and Pb are 18 and 120 mg/kg, respectively. More information about Eco-SSLs can be found at: http://www.epa.gov/ecotox/ecossl/.

For most common garden vegetables, the uptake of metals is not very high. For the most part, exposures would tend to come from consuming adhered soil on unwashed produce (i.e., fruits, like tomatoes, would be less of a problem than roots or tubers, although these are frequently scrubbed or peeled before consumption). Nevertheless, EPA generally cautions against gardening in areas of known contamination. Also, it may be advisable to NOT consume produce from a garden in the drip line of a home or building structure or from areas where contamination is known to be located.

Another source of exposure related to gardening is handling/intensive contact with contaminated soil and the potential for tracking the contaminated soil into the house (on tools, shoes, or clothing). Vegetables, hands, clothing, and tools should be cleaned before being brought indoors to reduce tracking contaminated soil into the residence.

Human health screening levels for arsenic vary by location throughout the US due to existing geological sources of arsenic, which are above generic background concentrations. However, a screening level of 40 mg/kg (milligrams per kilogram or parts per million) of arsenic is generally considering an appropriate screening level for soil arsenic (unrestricted residential contact with soils). While 400 mg/kg (milligrams per kilogram or parts per million) lead in soil is OSWER's human health soil screening concentration for lead (unrestricted residential contact with soils). These recommendations address concerns with track-in of contaminated soil and possible consumption of unwashed produce. The USEPA Technical Review Workgroup (TRW) Lead Committee developed the recommendations located in Table 1 for urban gardens. Based on the TRW's recommendations soils from the Einstein School and Las Monjas locations had soil lead concentrations below 100 mg/kg (milligrams per kilogram or parts per million), which indicates low risk for potential exposure to contaminated soils and produce. However, 2 soils from the El Pilar location

(Table 2C) had soils that may be of potential risk as the lead soil concentrations exceeded 100 mg/kg (milligrams per kilogram or parts per million). See Tables 2A-C for soil lead and arsenic concentrations.

For reported uptake rates in fruits and vegetables, several studies provide additional information on home grown produce and exposure to metals in soil and references are provided below.

Table 1. TRW Lead Committee Recommended Best Management Practices for Gardening in Lead Contaminated Areas

Soil-Lead Concentration (ppm)	Category	Recommendation: Gardening Practices	Recommendation: Choosing Plants[a]
<100	Low risk	• No specific remedial action needed. • Wash hands, produce, clothes (good gardening and housekeeping practices).	• No restrictions of crop types.
>100–400[b] -·-·-·-·-→ 400–1200	Potential risk	• Increasing use of good gardening and housekeeping practices as described in Table 3. • Relocate garden to lower risk garden areas. • Increasing use of soil amendments (*e.g.*, compost, clean fill), barriers (*e.g.*, mulch), and other remedial measures (see Table 3) up to and including raised beds and containers. • Ensure gardeners wear gloves and use tools to reduce soil contact and ingestion.	• Decrease planting of root vegetables or relocate root crop planting to lower risk areas. • Increase use of soil amendments and barriers to reduce soil deposition onto leafy vegetables. • Increase planting of fruiting vegetables, vegetables that grow on vines, and fruit trees.
>1200	High risk	• All of the above good gardening and housekeeping practices. • Raised beds, soil containers, soil replacement (*i.e.*, excavate contaminated soil and replace with soil containing low lead concentrations) are strongly recommended.[c] • Consider finding other locations for garden. • Restrict child access to only established safe areas. • Restrict all gardening by or for children in contaminated soils.	• Select plants with shallow roots for raised beds or areas with replacement soil to ensure that roots do not reach contaminated soil that is left in place, if any, otherwise, no restrictions.

[a] Source: Hemphill et al., 1973; Moir and Thornton, 1989; U.S. EPA, 1995; U.S. DOE, 1998; Jorhem et al., 2000; Heinegg et al., 2000; Finster

Bioaccessibility measurements

Human exposure to arsenic (As) in soils can have serious health impacts including increased cancer risk associated with ingestion of As-contaminated soils (Calabrese et al. 1996; Davis et al. 1991; Dudka and Miller 1999). Accurate assessment of human health risks from exposure to As-contaminated soils depends on estimating its bioavailability, which is defined as the fraction of ingested As absorbed across the gastrointestinal barrier and available for systemic distribution and metabolism. Arsenic bioavailability varies among soils and is influenced by site-specific soil physical and chemical characteristics and internal biological factors. U.S. Environmental Protection Agency guidance describes the need for development of soil As bioavailability methods and data to improve the accuracy of human exposure and risk calculations at As-contaminated sites (USEPA 2007). An understanding of arsenic bioavailability for dietary sources of arsenic is important when comparing total arsenic intakes across populations with different exposure patterns. Such patterns can affect the absorbed dose of arsenic, and thus also whether (and to what extent) an adverse effect occurs.

Bioaccessibility refers to the physiological solubility of arsenic and lead, which is *potentially* bioavailable for absorption from an environmental medium or diet fraction (e.g., soil, rice). The bioaccessible fraction of ingested arsenic/lead is the portion of arsenic/lead that is available for absorption from the wall of the gastrointestinal tract.

Arsenic and lead bioaccessibility was calculated and expressed on a percentage basis according to equation 1.

$$As\ bioaccessibility\ (\%) = \left(\frac{in\ vitro\ As}{total\ As} \right)\ x\ 100 \qquad \text{Eq. (1)}$$

Where:

In vitro As = As extracted during the in vitro assay
Total As = Amount of As in the contaminated soil used for bioaccessibility determination

Table 2. Total soil element concentrations determined by microwave digestion in accordance with EPA Method 3051 with analysis by Inductively Coupled Plasma-Optical Emissions Spectroscopy (ICP-OES) in accordance with EPA method 6010. In vitro bioaccessibility (IVBA) values determined in accordance with EPA method 9200.2-86 with analysis by Inductively Coupled Plasma-Mass Spectrometer (ICP-MS) in accordance with EPA method 6020C. Soils listed by site location. Total soil concentrations that exceed human health screening levels (40 ppm and 400 mg/kg for As and Pb, respectively) or recommended guidelines for urban gardens (only available for Pb) at 100 mg/kg are highlighted in red text.

Table 2A: Einstein School Site Soil Totals and IVBA results

Soil ID	As Totals (mg/kg)	± S.D.	As IVBA (%)	± S.D.	Pb Totals (mg/kg)	± S.D.	Pb IVBA (%)	± S.D.
tire 1	7.2[1]	0.9	24.0	0.0	41.7	4.5	71.9	4.0
box 2	5.2[1]	0.4	31.7	0.5	16.7	1.6	87.4	1.2
box 3	4.7[1]	0.3	37.2	NA	23.5	1.2	78.2	NA
box 3 Dup A	4.1[1]	2.8	42.0	0.4	18.9	9.4	100	2.5
soil box 4	9.3	0.2	31.3	1.2	44.9	0.0	74.3	0.2
box 4 Dup	8.6	0.4	30.8	0.4	39.6	1.7	75.2	2.1
ground 5	8.4	1.5	24.3	0.4	26.4	4.9	100	0.8
ground 5D	10.3	0.5	19.0[2]	0.5	32.2	1.8	84.6	2.6
E.Composite	8.1[1]	0.5	18.8[2]	0.5	35.6	2.6	68.1	2.3

Table 2B: Las Monjas (LM) Site Soil Totals and IVBA results

Soil ID	As Totals (mg/kg)	± S.D.	As IVBA (%)	± S.D.	Pb Totals (mg/kg)	± S.D.	Pb IVBA (%)	± S.D.
LM 1	9.0[1]	1.3	23.3	1.0	33.5	0.1	66.3	0.4
LM 1 Dup A	8.7[1]	0.7	24.3	1.6	35.6	1.8	64.6	5.9
LM 2	8.7[1]	0.4	23.4	0.4	34.9	1.4	68.3	0.1
LM 2 Dup B	9.2	1.2	23.7	0.2	37.9	1.9	67.1	1.7
LM 3	9.0	0.6	24.0	0.9	53.4	2.4	74.0	0.4
LM 3 Dup C	9.2	1.2	23.3[3]	0.8	57.3	6.5	71.1	3.0
LM 4	10.6	1.1	24.2[3]	0.1	39.0	2.2	77.6	1.1
LM 4 Dup D	10.0	0.7	26.7[3]	0.8	37.4	1.5	79.0	1.3
LM 5	6.1[1]	0.2	18.3[3]	0.3	21.9	1.2	63.1	5.1
LM 5 Dup E	5.4[1]	0.1	21.4	0.8	21.3	0.5	59.0	1.7
LM 6 Comp.	8.8	0.1	28.9	1.2	34.7	0.6	76.3	0.9

Table 2C: El Pilar (EP) Site Soil Totals and IVBA results

Soil ID	As Totals (mg/kg)	± S.D.	As IVBA (%)	± S.D.	Pb Totals (mg/kg)	± S.D.	Pb IVBA (%)	± S.D.
EP 1	55.4	3.4	31.6	0.1	130.9	29.3	74.1	4.1
EP 2	15.7	0.2	25.5	0.7	82.5	5.1	73.4	0.4
EP 2 Dup A	13.9	0.0	31.7	1.6	91.5	6.2	80.3	7.6
EP 3	10.5	0.6	16.7	0.1	59.2	1.7	64.3	0.5
EP 3 Dup B	12.1	0.6	21.0	0.4	53.9	2.7	65.7	0.7
EP 4	10.3	0.6	22.1	0.2	77.7	0.3	64.7	2.8
EP 4 Dup C	9.3	0.4	19.0	0.1	86.8	0.6	60.5	1.5
EP 5	12.8	1.1	20.0	0.2	59.2	1.3	63.6	0.1
EP 5 Dup D	11.3	0.1	20.0	1.2	50.1	0.1	57.7	0.4
EP 6 Comp.	14.1	0.4	26.1	1.6	172.0	13.1	77.5	5.8

[1] Values are estimates because ICP-OES raw values were below method reporting limits of 10 ppb for As

SD = standard deviation

Table 3. Plant tissue concentrations, determined by microwave digestion in accordance with EPA Method 3052 with analysis by Inductively Coupled Plasma- Mass Spectrometer (ICP-MS), paired with soil concentrations as presented in table 1. General plant concentrations within the conterminous USA for lead range from 0.7-7.2 mg/kg in background soils and 2.5-82 mg/kg in soils containing 200 mg/kg total lead. General plant concentrations within the conterminous USA for arsenic range from 0.1-1000 mg/kg (high concentrations found in rice and rice roots).

	As	± S.D.	Pb	± S.D.
	mg/kg		mg/kg	
Ein. Lettuce	0.87	0.00	2.85	0.03
Soil Box 3	4.7	0.3	23.5	1.2
Ein. Pumpkin	2.05	0.05	5.24	0.16
Soil 5D	10.3	0.5	32.2	1.8
Ein Basil[1]	0.31	-	0.44	-
Soil box 2	5.25	0.36	16.72	1.61
LM Eggplant	0.48	0.22	0.38	0.12
LM soil 2	8.7	0.4	34.9	1.4
LM Basil	0.66	0.00	2.13	0.05
LM soil 4	10.6	1.1	39.0	2.2
LM Yucca	0.17	0.00	0.2	0.01
LM soil 1	9.02	1.27	33.45	0.07
LM Cilantro[1]	3.2	-	8.6	-
LM soil 3	8.96	0.59	53.41	2.44
EP Avocado	0.51	0.03	0.22	0.02
EP soil 1	55.4	3.4	130.9	29.3
EP Tomatoes	0.03	0.01	0.09	0.00
EP soil 3 avg[1]	11.3	0.6	56.6	2.2
EP Pepper[2]	0.11	-	0.28	-
EP soil 2 avg[1]	14.81	0.11	87.00	5.67

[1] Avg values were used because there were duplicate site soil samples

[2] These plant samples only had enough mass to perform one extraction.

Table 4. Quality Assurance/Quality Control (QA/QC) summary for 3051 soil digestions for totals determination

QC	Limit*	frequency	As	Pb
blank	< 50 µg/L	once per batch	0 µg/L	0- 0.95 ug/L
blank spike	85 – 115 % recovery	once per batch	89 – 100 %	91– 103 %
matrix spike	75 – 125 % recovery	once per batch	95 - 101 %	94 - 121 %
Control soil (NIST 2710A)	Relative percent recoveries **	once per batch	88 – 103 %	87 – 101 %

***** EPA method 3051 does not define specific QC limits. Limits defined here have been set by EPA RTP bioavailability lab.

** Percent recoveries have been normalized to reflect the normal percent recoveries as given in NIST certification.

µg/L = micrograms/liter

Table 5: QA/QC summary for Method 3052 plant tissue digests

QC	Limit*	frequency	As	Pb
bottle blank	< 50 µg/L	once per batch	0 µg/L	0.03 µg/L
blank spike	85 – 115 % recovery	once per batch	101 – 102 %	102 – 105 %
Control soil (NIST 2710A)	85 – 115 % recovery **	once per batch	100 – 113 %	88 – 99 %

***** EPA method 3052 does not define specific QC limits. Limits defined here have been set by EPA RTP bioavailability lab.

** Percent recoveries have been normalized to reflect the normal percent recoveries as given in NIST certification.

µg/L = micrograms/liter

Table 6. QA/QC summary table for EPA Method 9200.2-86 IVBA extractions

QC	Limit*	frequency	As	Pb	Pass (Y/N) ?
unprocessed	< 25 µg/L	once per batch	0– 0.1 ppb	0 – 1.2 ppb	Yes
bottle blank	< 50 µg/L	once per batch	0 – 1.1 ppb	0.3 – 8.3 ppb	Yes
blank spike	85 – 125 % recovery	once per batch	98 – 120 %	97 – 115 %	Yes
duplicate sample	< 20 % standard deviation	each soil	0 – 1.6 % S.D.	0.1 – 7.6 % S.D.	Yes
Control soil (NIST 2710A)	85 – 125 % recovery	once per batch	99 – 120 %	95 – 110 %	Y

µg/L = micrograms/liter

S.D. = standard deviation

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