Landscape and Urban Planning 175 (2018) 184–194

Contents lists available at ScienceDirect

Landscape and Urban Planning

journal homepage: www.elsevier.com/locate/landurbplan

Research Paper

Constructed soils for mitigating lead (Pb) exposure and promoting urban community gardening: The New York City Clean Soil Bank pilot study

Sara Perl Egendorf[a,b,c,g,*], Zhongqi Cheng[a,b,g], Maha Deeb[a,c,g], Victor Flores[a,g], Anna Paltseva[a,b,g], Daniel Walsh[d,e], Peter Groffman[a,b,c,g], Howard W. Mielke[f]

[a] Brooklyn College of The City University of New York, Department of Earth and Environmental Sciences, 2900 Bedford Avenue, Brooklyn, NY, United States
[b] Graduate Center of The City University of New York, PhD Program in Earth and Environmental Sciences, 365 5th Avenue, New York, NY, United States
[c] Advanced Science Research Center of The City University of New York, 85 St. Nicholas Terrace, New York, NY, United States
[d] Columbia University, Lamont Doherty Earth Observatory, Route 9W, Palisades, New York, United States
[e] New York City Mayor's Office of Environmental Remediation, 100 Gold Street, New York, NY, United States
[f] Tulane University School of Medicine, New Orleans, LA, United States
[g] New York City Urban Soils Institute, 2900 Bedford Avenue, Brooklyn, NY, United States

ARTICLE INFO

Keywords:
Compost
Contamination
Glacial sediments
Manufactured soil
Technosol
Urban agriculture

ABSTRACT

Gardening provides a wide range of benefits to urban residents but may also increase risks of exposure to contaminants in soils. Here we evaluate the use of clean excavated glacial sediments and locally produced compost, to create soils for urban gardens in New York City, NY, USA. The objectives of this study are to examine contaminants in compost and manufactured soil, assess safety of produce, and evaluate the agronomic value of soil mixes with different ratios of sediment and compost. Methods of analysis include quantifying metal/metalloid concentrations in sediments, composts, and plant tissues, soil agronomic parameters (pH, salinity, organic matter, total nitrogen, total carbon), and crop yield. Contaminant levels in sediments from the New York City Clean Soil Bank (CSB) (< 10 mg Pb kg^{-1}) were far below background levels of soils in two selected gardens (66 and 1025 mg Pb kg^{-1}), while available composts had highly variable levels of contamination (10–232 mg Pb kg^{-1}). A relatively clean compost was used for this study (19 mg Pb kg^{-1}). Metal/metalloid levels did not increase in constructed soils during the 1-year pilot study period, and crops were well below EU safety standards of 0.1 and 0.3 mg Pb kg^{-1} for fruits and leafy greens, even when surrounded by contaminated soils. Sediment/compost mixtures produced yields comparable to control plots. Results suggest that CSB sediments have high potential to serve as manufactured topsoil. Creating these soil mixtures diverts materials from expensive waste disposal, reduces contamination risks for urban residents, and promotes the myriad benefits of urban agriculture and community gardening.

1. Introduction

Urban community gardening exists at the critical intersection between urban sustainability and environmental justice. Gardens in the midst of cities provide green space and myriad ecosystem services, which include but are not limited to air purification, carbon sequestration, water filtration, and stormwater capture (Gittleman, Farmer, Kremer, & McPhearson, 2016; Goddard, Dougill, & Benton, 2010; Lin, Philpott, & Jha, 2015; McPhearson, Kremer, & Hamstead, 2013; Yadav, Duckworth, & Grewal, 2012). Gardens provide residents with ways to interact with nature that may otherwise be lacking in a major metropolis. Whether gardening occurs within cities or in rural areas, it has proven beneficial for cardiovascular (Caspersen, Bloemberg, Saris, Merritt, & Kromhout, 1991; Magnus, Matroos, & Strackee, 1979), mental (Fabrigoule et al., 1995; Kaplan, 1973) and the overall health of its practitioners (Armstrong, 2000; Twiss et al., 2003; Wakefield, Yeudall, Taron, Reynolds, & Skinner, 2007). City gardening also provides opportunities for growing affordable and healthy produce, promoting food sovereignty and food justice, despite numerous obstacles to such goals (Alaimo, Packnett, Miles, & Kruger, 2008; Litt et al., 2011; McCormack, Laska, Larson, & Story, 2010; Meenar & Hoover, 2016; Ramírez, 2015; Sbicca & Myers, 2017). These activities also have the potential to increase social cohesion and collective agency within communities (Blair, Giesecke, & Sherman, 1991; Hung, 2004; Okvat &

Abbreviations: (CSB), Clean Soil Bank; (NYC), New York City; (OER), Mayor's Office of Environmental Remediation; (NYS), New York State; (SCOUU), Soil Cleanup Objective Unrestricted Use criteria; (OM), organic matter

* Corresponding author at: Graduate Center of The City University of New York, PhD Program in Earth and Environmental Sciences, 365 5th Avenue, New York, NY, United States.
E-mail address: segendorf@gradcenter.cuny.edu (S.P. Egendorf).

https://doi.org/10.1016/j.landurbplan.2018.03.012
Received 21 November 2017; Received in revised form 1 March 2018; Accepted 15 March 2018
Available online 09 April 2018
0169-2046/

Zautra, 2011; Saldivar-Tanaka & Krasny, 2004; White, 2011). In New York City, community gardening efforts were initiated and fostered over the past several decades by people of color and people from low-income backgrounds who continue to fight to maintain gardens on land in a city where real estate prices are among the highest in the country (Angotti, 2015; Aptekar, 2015; Eizenberg, 2012; Reynolds, 2015).

While urban gardening promotes environmental justice and sustainability, the widespread presence of soil contaminants poses significant health risks. Though people from vulnerable populations may reap the aforementioned benefits of gardening, they may also be the most at risk for contaminant exposure. Generally located on previously vacant lots, urban gardens are often created in the presence of contaminants such as lead (Pb), arsenic (As), cadmium (Cd), nickel (Ni), zinc (Zn), mercury (Hg), polycyclic aromatic hydrocarbons (PAHs), and volatile organic compounds (VOCs) (Marquez-Bravo et al., 2016; McBride et al., 2014; Mitchell et al., 2014; Spliethoff et al., 2016). Low-income people of color are disproportionately located in areas of high soil Pb contamination in NYC (Cheng et al., 2015). This is a phenomenon that occurs throughout the U.S. and other countries, a result of numerous ongoing historical, social, and spatio-temporal processes that replicate patterns of environmental health disparities and necessitate movements to promote environmental justice (Aelion, Davis, Lawson, Cai, & McDermott, 2013; Filippelli & Laidlaw, 2010; McClintock, 2015).

Lead is a pollutant of particular concern in urban environments, especially for children (Mielke, 2015). Although the Toxic Substances Control Act (TSCA) banned the use of lead-based paint in 1978 (USEPA., 1978) and the Clean Air Act banned the sale of leaded gasoline in 1996 (USEPA., 1970), anthropogenic Pb derived from these as well as other sources including pipes and solder, industrial activities, and waste incineration, has resulted in high accumulations of Pb in urban soils. Lead cannot be broken down or leached out of soils, except in acidic conditions (Alloway, 2010; Cheng, Lee, Dayan, Grinshtein, & Shaw, 2011). Lead contaminated soils and dusts are subsequently re-suspended and redistributed around cities (Zahran, Laidlaw, McElmurry, Filippelli, & Taylor, 2013), and have been identified as an important source of Pb exposure for urban populations (Mielke & Reagan, 1998). Dominant pathways for exposure to Pb from soil include direct ingestion of Pb attached to soil particles, ingestion of produce with Pb in the matrix or on the surface, and inhalation of Pb dust (Mielke, 2016).

The most effective strategies for mitigating Pb-contaminated soil exposure include excavating and replacing, incorporating amendments to reduce contaminant concentrations or bioavailability, or covering with a clean soil (Laidlaw et al., 2017). One of the most widely adopted Best Management Practices (BMPs) for urban gardening is the construction of raised beds (USEPA., 2014). The challenge for replacing contaminated materials or building raised beds is the availability of clean soil (Mielke, 2016). A few centimeters of naturally occurring soil can take thousands of years to form, and transporting soils from rural areas is expensive and depletes the ecosystems from which they are taken (Brady & Weil, 2017). However, compared with dig and haul management of contaminated soil at 388 US$/m^2 (in 2011), importing soils from outlying and rural areas is relatively inexpensive at 22 US $/m^2 (Laidlaw et al., 2017; Mielke, 2016). The U.S. Geological Survey identified clean, low Pb non-urban soils surrounding all U.S. cities (Gustavsson, Bølviken, Smith, & Severson, 2001). In the densely populated landscape of NYC, large quantities of clean, inexpensive, and locally sourced soil are urgently required to address the issue of urban soil contamination, particularly for gardening and agriculture.

The potential for waste stream materials to meet urban soil needs are being evaluated. As developers build on previously vacant lots in Brooklyn and Queens, NYC, sediments from depth are excavated. While Manhattan and the Bronx are underlain by crystalline bedrock, Brooklyn and Queens, geographically located on Long Island, have developed on glacially deposited sediments. Excavated sediments are usually not contaminated, but most are nonetheless transported outside of the city due to a lack of space and infrastructure for their local use. In an effort to address this waste or distant use of clean material, the NYC Mayor's Office of Environmental Remediation (OER) created the Clean Soil Bank (CSB) Program (CSB; Walsh et al., 2018). Since 2013, OER has used the CSB to exchange 4.2×10^5 tons of glacial sediments from development sites and has diverted them for beneficial uses within NYC (Walsh et al., 2018).

The glacial sediments excavated from development sites lack the organic matter and nutrient content needed for them to be effective as growing media. Compost production is proliferating in cities, and organic waste recycling initiatives in NYC are generating large quantities of compost with the aim of reducing the volume of organic waste being sent to landfills. There is great potential for and interest in using this material as a source of both organic matter and nutrients for urban gardens (Brown, Kurtz, Bary, & Cogger, 2011).

While there is a growing body of scholarly work examining the issue of soil contamination and approaches for mitigating contaminant exposure both in the U.S. and abroad (Alloway, 2010; Biasioli et al., 2007; Delbecque & Verdoodt, 2016; Kelly & Thornton, 1996), there is only a limited number of studies examining the use of manufactured soils or constructed Technosols for this purpose (Sere et al., 2008). Sloan, Ampim, Basta, and Scott (2012) implore soil scientists to address the need for constructed soils in urban settings. While the use of organic amendments, such as compost or biosolids has been investigated, relatively few peer-reviewed articles have been published on inorganic substrates and manufactured soils.

Research in the U.S. evaluating the use of sediments as a soil matrix has focused on materials dredged from lakes or rivers. Brandon and Price (2007) studied the use of aquatic sediments and outlined an approach for manufacturing soil. The Army Corps of Engineers dredges more than 300 million cubic yards of sediments across the U.S. annually (Brandon & Price, 2007), and in many cases these sediments have been found to be appropriate for agricultural purposes (Darmody & Marlin, 2002; Lembke et al., 1983) even with somewhat elevated levels of trace metals (Darmody et al., 2004).

The use of terrestrial or glacially deposited sediments, like those in the CSB, has been examined for reconstruction of derelict lands in France (Sere et al., 2008). These materials were evaluated for their agronomic properties (Rokia et al., 2014) and their hydrostructrual properties (Deeb, Grimaldi, Lerch, Pando, Podwojewski, & Blouin, 2016, Deeb, Grimaldi, Lerch, Pando, Gigon, Blouin, 2016). These authors demonstrate that soil construction from locally available technogenic parent materials can meet the urgent needs for clean and productive urban soil, while reducing the volume of materials entering the waste stream.

The purpose of this research is to contribute to this area of inquiry by evaluating the use of glacial sediments and compost to manufacture topsoil for urban agricultural use. The focus of this study is on contaminants in the manufactured soil, safety and yield of the produce, and the agronomic value of soil mixtures with different ratios of sediment and compost. This study addresses the following questions: Do the manufactured soils contain contaminants at levels of concern and will they become more contaminated over time? Will experimental crops be safe for human consumption, considering the levels of contaminants in compost and the surrounding environment? Which sediment/compost ratio is required to produce adequate yield?

2. Materials and methods

2.1. Field methods

2.1.1. Community garden test sites

Experimental test sites were established in three community gardens in three different neighborhoods in Brooklyn, NY, USA. The New York City Department of Parks and Recreation (DPR) branch that manages community gardens, GreenThumb, oversees all three gardens and the Brooklyn Queens Land Trust jointly supports one of the gardens. Gardens were selected on the basis of available space, gardener interest in collaboration, as well as varying uses and histories. Garden 1 is a large farm that sells food at local farmers markets, Garden 2 was newly established at the onset of the growing season, and Garden 3 has been cultivated by community members since 1996. Historical information on each garden was gathered through GreenThumb records and communication with garden coordinators. Background garden soils were analyzed for metal contaminants by portable X-ray Fluorescence (XRF) scanner (Olympus Inc, Delta Classic) in the field, and later by Inductively Coupled Plasma Mass Spectrometry (ICP-MS) (Perkin Elmer, Elan DRCe) (see Section 2.2.1 for sampling and analytical methods).

2.1.2. Construction of raised beds

Four raised beds were constructed in Gardens 1 and 2 with 5 cm × 25 cm untreated pine lumber. Raised bed frames (1.2 m × 2.4 m long) were placed above the garden soil and landscape fabric was placed within each frame to enable drainage but prevent both root penetration and mixing with underlying soil.

Three of the beds were filled with CSB sediments and compost at three different volumetric ratios: 50:50, 67:33, and 80:20. Compost, created from food scraps and wood chips, was donated by the Gowanus Canal Conservancy (GCC). After low metal concentrations were verified by XRF, compost was delivered to each of the three garden sites and manually mixed with sediments. The fourth bed in Gardens 1 and 2 was established as a control and filled with topsoil purchased by DPR from a local vendor for use in gardens across the city. Raised beds were established in June 2015. Due to space limitation in Garden 3, only one 1.2 m × 1.2 m raised bed was built, filled with sediments and compost at the volumetric ratio of 67:33. Other adjacent plots in Garden 3 contained in situ soil with high concentrations of Pb and As (Table 1). As soon as these contaminants were identified in Garden 3, all gardeners were made aware of the issue. These plots were contained within a fenced area and have since been used exclusively for scientific inquiry.

2.1.3. Crop selection and cultivation

Fruit and vegetable seedlings representing common varieties used by community gardeners were supplied by DPR. A range of crops with variable metal and metalloid accumulation rates and tendencies for particle adherence were purposely selected from available seedlings. Seedlings were planted in beds two to three weeks after raised bed construction. Gardens 1 and 2 were planted with basil, cabbage, cilantro, eggplant, onion, kale, peppers, tomato, and zucchini. Garden 3, with a smaller bed, was planted with cilantro, eggplant, kale, onion, and tomato. Leafy green crops (i.e. basil, cabbage, cilantro, kale) with high surface area and root vegetables (i.e., onion) with increased contact with soil present higher risk for particle adherence and entrapment than fruiting crops (i.e. tomato, pepper, eggplant and zucchini) (Alexander, Alloway, & Dourado, 2006; Brown, Chaney, & Hettiarachchi, 2016; Finster, Gray, & Binns, 2004; McBride et al., 2014; Samsøe-Petersen, Larsen, Larsen, & Bruun, 2002). Each garden site was watered, weeded, and tended to at least twice weekly by researchers, with occasional watering assistance by gardeners.

2.2. Laboratory methods

2.2.1. Contaminants in CSB sediments, composts, and soils

Composite samples were created by taking samples from the top 15–20 cm of eight points in each bed or walkway area. Samples were thoroughly mixed in a clean plastic bucket, and approximately 0.5 L was kept in a clear plastic bag. Constructed soils and the control topsoil were sampled three weeks after placement in beds, and samples were retaken in October 2015 and July 2016. Field screening of background garden soils and composts by XRF occurred for 90 seconds and means of three replicates were recorded for As, Cu, Ni, Pb, and Zn. Samples were mixed between scanning intervals.

Three different particle size fractions of selected composts were analyzed by XRF: greater than 2.83 mm, 2.83–2.0 mm, and less than 2.0 mm. Air-dried composts were passed between standard sieves, and each fraction was placed in clear plastic bags and analyzed by XRF as described above.

CSB sediments and soils were also analyzed by Inductively Coupled Plasma Mass Spectrometry (ICP-MS) (Perkin Elmer, Elan DRCe). Soils were dried to constant weight at 105 degrees C, and the < 2 mm fraction was subjected to acid digestion using a microwave oven (EPA Method 3051; USEPA, 2007). Concentrations of As, Cd, Cr, Cu, Ni, Pb and Zn were determined by ICP-MS (EPA Method 6020; USEPA, 1998). External reference materials SRM-2586 and SRM-2587 obtained from the National Institute of Standards and Technology were used to check for accuracy of the measurements (NIST, 2013, 2017). Each digestion batch of up to 22 samples included two reference standards, two blanks, and at least one duplicate. Germanium (Ge) and Bismuth (Bi) were used as internal standards for instrumental drift correction.

2.2.2. Contaminants in crops

All harvested crops were collected in plastic bags, soaked in tap water in bags, and rinsed three times. Triplicate washing was performed to remove soil particles and represent washing techniques that gardeners could employ at home. Crops were dried in open plastic bags on a clean laminar flow bench. Samples were then cut into small pieces, and thoroughly mixed and stored in plastic bags in a freezer, if not digested within a week. A minimum of 27 samples of each crop were analyzed, three samples from each of the nine beds.

Plant tissues were analyzed for metal concentrations using microwave oven digestion (modified EPA Method 3052; USEPA, 1996). Approximately 5 g of each sample was digested with 10 mL of 50% HNO_3

Table 1
Mean ± SE (n = 8), metal contaminants (mg kg^{-1}) in Clean Soil Bank sediments (CSB S) used in this study, and background soils (BG) from gardens 1 and 3. Mean ± SE (n = 4), metal contaminants (mg kg^{-1}) in CSB S and compost volumetric percentage admixtures (CSB 20%, CSB 33%, CSB 50%) used in the study and in purchased control soils (CON). Analyses were conducted directly after mixing soils in June 2015. NYS Department of Environmental Conservation Soil Cleanup Objectives (SCO) Unrestricted Use (UU) criteria are listed for comparison.

Soil Type	Metal Concentrations (mg kg^{-1})				
	As	Cu	Ni	Pb	Zn
CSB S	3 ± 0.7	12 ± 2.8	14 ± 3.0	10 ± 1.0	49 ± 9.4
BG 1	6 ± 0.6	53 ± 6.1	15 ± 0.7	66 ± 4.0	150 ± 10.3
BG 3	142 ± 14.9	328 ± 30.5	NA	1025 ± 46.4	1474 ± 31.7
CON	3 ± 0.7	23 ± 1.9	8 ± 1.8	33 ± 5.5	89 ± 47.1
CSB 20%	2 ± 0.6	15 ± 2.8	10 ± 0.9	10 ± 2.1	59 ± 19.8
CSB 33%	1 ± 0.4	14 ± 0.6	15 ± 5.7	8.6 ± 2.5	59 ± 22.1
CSB 50%	1 ± 0.4	18 ± 1.4	10 ± 1.1	18 ± 5.2	81 ± 26
SCO UU	13	50	30	63	109

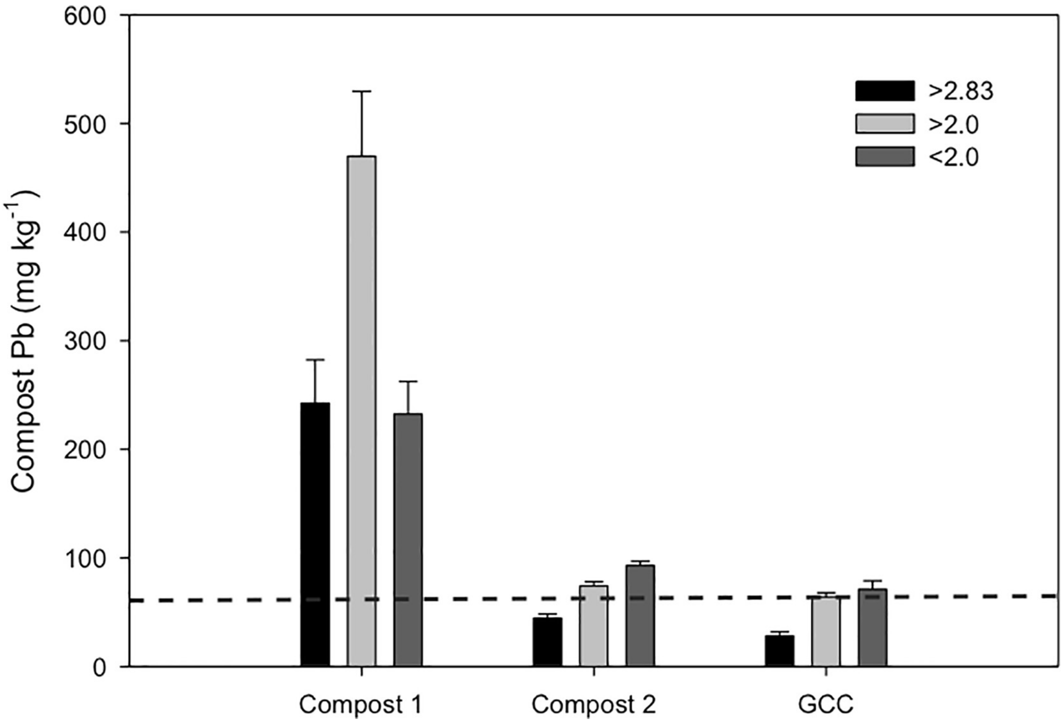

Fig. 1. Mean ± SE (n = 6) Pb concentration in three size fractions (> 2.83 mm, 2.0–2.83 mm, < 2.0 mm) of the three different composts considered for mixing with CSB sediments. The Gowanus Canal Conservancy compost (GCC) was chosen for use in this study. Dashed horizontal line represents NYS Department of Environmental Conservation Soil Cleanup Objectives Unrestricted Use (SCOUU) criteria for Pb.

acid in the microwave oven digester. The samples were analyzed with ICP-MS for As, Cd, Cr, Co, Cu, Ni, Pb, Zn, and Al (EPA Method 6020: USEPA, 1998). To ensure precision and check for accuracy of the measurements, each batch of 22 samples was digested with at least one duplicate, two blanks, and both apple leaf and rice flour Standard Reference Materials (SRM 1515 and SRM 1568a).

2.2.3. Agronomic properties of soils and crop yields

Soil parameters were determined following USDA Kellogg Soil Survey Laboratory Methods (Soil Survey Staff, 2014). The pH of each soil was measured in a 1:1 slurry using a combined electrode (Fisher Science Education). Salt content was determined in a 1:2 slurry for Total Dissolved Solids (TDS) with an Oakton TDS 6 Acorn series meter. Total Organic Content (TOC) was determined by Loss on Ignition with a Barnstead Thermolyne tabletop furnace (1300 series). Organic carbon and total nitrogen were determined by CHN analyzer (ThermoFinnigan Flash EA 1112) (McGeehan & Naylor, 1988).

All crop harvests were taken by researchers. Leafy greens were harvested 47 days after planting. Onions were harvested 70 days after planting. All other fruits and vegetables were harvested periodically and picked when each yield appeared to be ripe. Final harvest of all produce was taken 135 days after planting. Upon harvest, crops were weighed and processed in the lab.

2.2.4. Statistical analyses

Statistical analyses were performed with the R 3.0.3 software (R Core Team, 2014). Normality and homogeneity of the data were evaluated using Shapiro and Bartlett tests. Since the data were not normally distributed, medians were compared using Kruskal-Wallis tests, and differences between multiple factors were compared by Nemenyi's test (Zar, 2010). Differences were considered significant when $p < 0.05$. The correlation between Pb and Al on all crops was tested with linear regression models.

3. Results

3.1. Contaminants in CSB sediments, composts, and soils

3.1.1. Contaminants in CSB sediments and background garden soils

The CSB sediments had extremely low organic contaminant concentrations below all detection limits (data not shown) and extremely low metal and metalloid concentrations (Table 1). The results presented here are consistent with results reported by OER wherein analyses were conducted by a certified commercial lab (York Analytical Laboratories) (Walsh et al., 2018). Both laboratories found that inorganic contaminants were well below the most stringent standards (Unrestricted Use, UU) of the NYS Department of Environmental Conservation (DEC) Soil Cleanup Objectives (SCO), hereby referred to as SCOUU (NYSDEC, 2006), which are 13 mg As kg^{-1}, 30 mg Cr kg^{-1}, 50 mg Cu kg^{-1}, 30 mg Ni kg^{-1}, 63 mg Pb kg^{-1}, and 109 mg Zn kg^{-1}.

Background garden soils were sampled for Gardens 1 and 3. Garden 2 was not sampled because it was newly constructed, and over one foot of mulch covered the entire garden. Garden 1 background soils were below the SCOUU criteria for As and Ni, but slightly above criteria for Cu, Pb, and Zn at 53, 66, and 150 mg kg^{-1} respectively (Table 1). Garden 3 background soils had contaminant concentrations well above the SCOUU threshold and were generally an order of magnitude higher, with 142 mg As kg^{-1}, 328 mg Cu kg^{-1}, 1025 mg Pb kg^{-1}, and 1474 mg Zn kg^{-1}. Only one small fenced area in Garden 3 contained such high contaminant concentrations, and this area has not been cultivated by gardeners since being recognized. CSB sediments had metal and metalloid concentrations well below SCOUU criteria and background soils from both gardens with 3 mg As kg^{-1}, 12 mg Cu kg^{-1}, 14 mg Ni kg^{-1}, 10 mg Pb kg^{-1}, and 49 mg Zn kg^{-1}.

3.1.2. Contaminants in compost

Compost sources were screened in the field for contaminants prior to use. Two composts from an unknown vendor contained a range of contaminants, with Pb ranging from 36 to 232 mg kg^{-1} and 34 to

129 mg kg^{-1}, respectively. These composts were not used in the study. A food waste and wood chip compost supplied by the Gowanus Canal Conservancy (GCC) had Pb concentrations ranging from 10 to 43 mg kg^{-1}, with a median of 19 mg kg^{-1} (n = 13). A second pile of compost was also sampled at GCC and had Pb concentrations ranging from 7 to 226 mg kg^{-1}, with a median of 45 mg kg^{-1} (n = 13). Only two of the 13 samples taken from this pile had Pb concentrations above 70 mg kg^{-1}. All of the compost in the first pile (about 4 cubic yards) was used for the study, and less than half of one cubic yard of the second pile was used to create sufficient volume. Although two of the samples from the second pile contained Pb concentrations above SCOUU criteria, the small volume of this material nonetheless created soil mixtures with Pb concentrations below these stringent standards (Table 1).

Each of these composts were subsequently analyzed for Pb concentrations by size fraction in the lab (Fig. 1). Compost 1 had Pb concentrations over 200 mg kg^{-1} in all fractions, with the 2.0–2.83 mm fraction over 450 mg kg^{-1}. Compost 2 had lower Pb concentrations overall (45–93 mg kg^{-1}), with increasing concentrations in the smaller particle sizes. The GCC compost, used for the field study, had the lowest Pb concentrations (29–65 mg kg^{-1}) and showed increasing concentrations with reduced particle sizes.

3.1.3. Contaminants in CSB mixed soils and control soil

After the CSB sediments and compost were mixed and placed into raised beds in gardens, composite samples of each bed were analyzed for the presence of organic and inorganic contaminants by York Analytical Laboratories (Walsh et al., 2018). The soils were also analyzed for inorganic contaminants at Brooklyn College (Table 1) in order to compare laboratory variability. The control soil and all CSB mixtures had metal concentrations below SCOUU criteria. The purchased control soil (CON) had higher concentrations of As, Cu, Pb, and Zn and lower Cr and Ni than all CSB-compost soils.

3.1.4. Contaminants in CSB soils over time

The experimental soil from each plot was sampled and analyzed for the presence of contaminants over the course of one year after emplacement in beds. Metal and metalloid contaminant concentrations varied slightly, but did not change significantly over time ($p = 0.3$) and the values for Pb concentrations are presented (Fig. 2). Organic contaminant concentrations also remained under detection limits over this year (data not shown). All metal and metalloid concentrations remained well below SCOUU criteria, and Pb for example, is shown to range from 5 to 30 mg kg^{-1} over the initial year. None of the three sites showed an increase in contamination over one year, even though there was variable contamination in background soils, i.e., Garden 3 contained soils with elevated Pb and As concentrations (Table 1).

3.2. Contaminants in crops

3.2.1. Lead in fruit and vegetable crops

Organic contaminant concentrations in crops were analyzed at York Analytical Laboratory and were below detectable limits. Metal and metalloid concentrations were above limits of detection, but were below health based guidance values established by the European Commission (EC, 2006). Fruit and root crops (Fig. 3a) had Pb concentrations below the safety threshold of 0.1 mg kg^{-1} fresh weight (f.w.) and leafy vegetables (Fig. 3b) had concentrations below the safety threshold of 0.3 mg kg^{-1}.

Although some crops had slightly higher concentrations than others, namely onions and basil, these differences were not concerning, because these concentrations were still well below respective safety thresholds. While Pb in soil mixtures increased slightly with increasing compost ratios (Table 1), Pb concentrations in plant tissues were not significantly different between different compost ratio beds ($p = 0.6$).

3.2.2. Relationship between Pb and Al in produce

The trace amounts of Pb found in crops could be the result of uptake by roots (which is mediated by factors such as soil pH, organic matter and Pb sorption reactions) or from soil particles adhered to plant tissues and foliar uptake (which is mediated by the surrounding environment and plant physiology) (Nabulo, Oryem-Origa, & Diamond, 2006; Schreck et al., 2012; Uzu, Sobanska, Sarret, Muñoz, & Dumat, 2010). Assuming that Al uptake is negligible in the neutral to slightly alkaline soils, the presence of Al on crops can be used as an indicator of minerals adhered to or entrained in plant tissues (McBride et al., 2014). The highest Pb concentrations were found on basil, and the correlation between Pb and Al was strong ($R^2 = 0.7$, $p < 0.001$), suggesting that tissue Pb was dominated by adherence rather than uptake. A linear correlation was also found for kale ($R^2 = 0.2$, $p = 0.02$) and peppers ($R^2 = 0.2$, $p = 0.02$). Statistically insignificant, weaker correlations were found for cabbage ($R^2 = 0.1$, $p = 0.16$), eggplant ($R^2 = -0.05$, $p = 0.8$), and tomato ($R^2 = 0.02$, $p = 0.2$).

3.3. Agronomic properties

3.3.1. Agronomic properties of soils

CSB sediments were analyzed for nutrient content prior to mixing, and low concentrations of soil organic carbon (SOC) (0.1 mg kg^{-1}) and nitrogen (N) (below detection limits) validated the need for mixing with compost. Each constructed soil was alkaline, as was the control soil (Table 2). Salt content (measured by Total Dissolved Solids, or TDS), organic matter (OM) and SOC were slightly higher in the control soil than in the 20% and 33% compost ratios, but was the highest in the 50% compost ratio beds. Total N was the highest in the 50% compost ratios, and was nearly the same in the other compost ratio beds as the control. Carbon to nitrogen ratios, however, were the highest in the control soil, and were nearly the same in each of the CSB compost ratio beds.

3.3.2. Crop yield

Mean harvest weights of total edible yield from each raised bed in Gardens 1 and 2 were calculated (Fig. 4). The constructed soils with 50% compost had the highest yield for all selected crops. The 33% compost beds produced comparable yields to the control soil bed, with the former having the second highest yield for basil, eggplant, kale, pepper, and tomato. The control soil produced higher yields than the 33% beds only for cabbage, and produced more than the 20% beds for kale, onion, and tomato.

4. Discussion

4.1. Contaminants in CSB sediments, composts, soils, and crops

The CSB sediments clearly can be used to construct clean topsoil for urban community gardens. The first step in any such construction is confirming the safety of sediments (Brandon & Price, 2007). The sediments here contained lower contaminant concentrations than background soils of the selected gardens (Table 1), three different urban composts (Fig. 1), garden soils from NYC in general (Cheng et al., 2015), and dredged sediments from waterways (Brose et al., 2016).

In order to produce a viable topsoil blend with sediments, organic matter additions are necessary (Deeb, Grimaldi, Lerch, Pando, Podwojewski, et al., 2016, Deeb, Grimaldi, Lerch, Pando, Gigon, et al., 2016; Epstein, Taylor, & Chaney, 1976; Kelling, Peterson, & Walsh, 1977; Paradelo & Barral, 2013; Reeves, 1997). However, obtaining uncontaminated sources of organic matter can be challenging in urban areas, as two different potential sources for this study were initially rejected, each with varying Pb concentrations in different size fractions (Fig. 1). Even though the GCC compost had low contaminant concentrations, it nonetheless contributed the majority of metal contaminants in the constructed soil (Table 1). Although all metals of

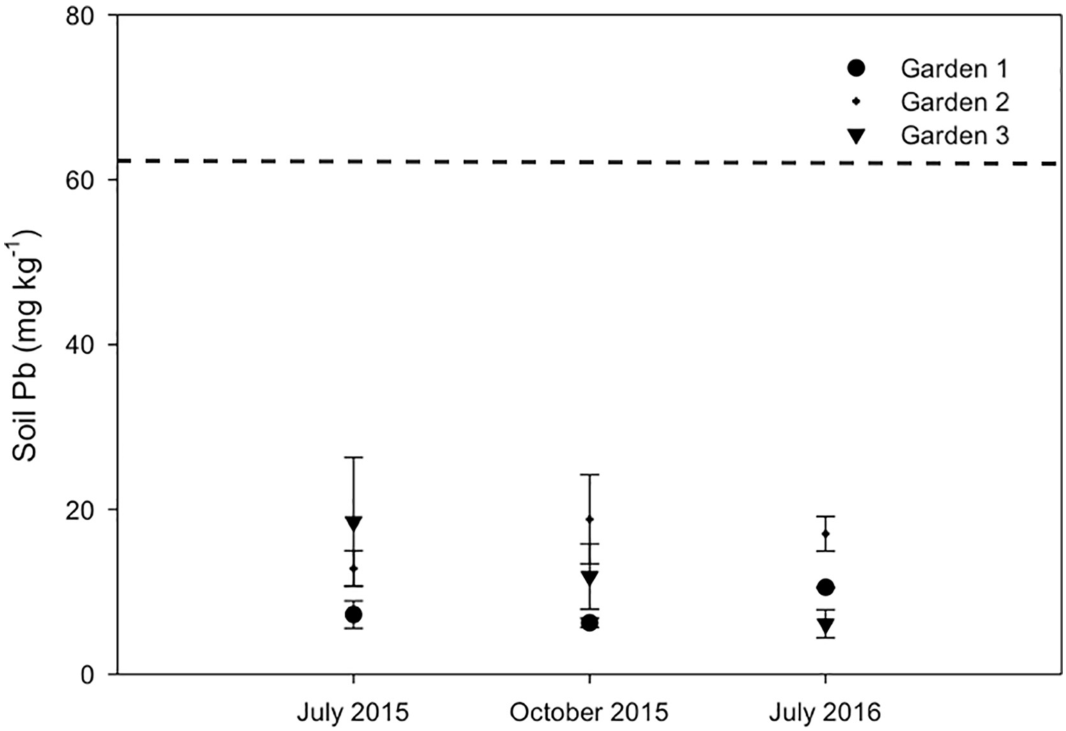

Fig. 2. Mean ± SE (n = 9) soil Pb concentrations from July 2015 to July 2016. Values are means of samples from all three Clean Soil Bank and compost experimental mixtures per garden.ashed horizontal line represents NYS Department of Environmental Conservation Soil Cleanup Objectives Unrestricted Use (SCOUU) criteria for Pb.

concern were well below the NYS SCOUU criteria in the constructed soil, compost decomposes over time, and thus there is potential for metals to accumulate in beds with subsequent organic matter additions (Smith, 2009).

On the other hand, a number of studies have found that metals such as Pb are less phytoavailable and bioavailable in compost than in soils, biosolids, or other media (Epstein, Chaney, Henry, & Logan, 1992; Farrell & Jones, 2009; Fitzstevens, Sharp, & Brabander, 2017; Hargreaves, Adl, & Warman, 2008; Kupper, Bürge, Bachmann, Güsewell, & Mayer, 2014). Composts are by nature heterogeneous, and depending on the feedstocks and quantity of sourced material, some will be more contaminated than others. Careful monitoring and screening for contaminants in compost is therefore necessary. Undertaking a comprehensive urban compost screening program would be resource intensive and logistically challenging, but there appears to be great interest in ensuring the quality of compost by both producers and consumers in NYC and surrounding regions. New methods for determining the biogeochemical fingerprint of Pb in urban composts are being actively developed (Fitzstevens et al., 2017; Sharp & Brabander, 2017).

Contaminant concentrations in the soils did not change significantly over the one-year study period, and the example of Pb is illustrated (Fig. 2). While no additional amendments were added to soils, there is a growing body of literature which suggests that resuspended soils from

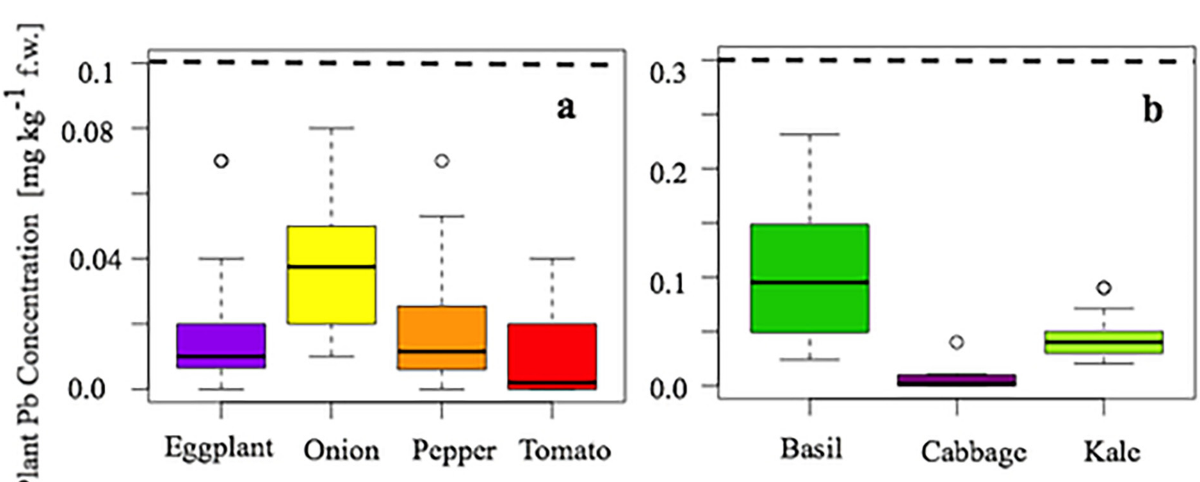

Fig. 3. Lead concentrations (mg kg^{-1}) fresh weight (f.w.) in fruit and vegetable crops grown in Clean Soil Bank soils in gardens 1, 2, and 3. The box plots show the lower quartile, the median and the upper quartile, with whiskers extending to the most extreme data point unless outliers are present, which are indicated as open circles. Dashed horizontal lines represent European Commission standards (EC, 2006) for Pb in fruiting (a) and leafy green crops (b). Sample sizes for each crop were: eggplant (n = 24), onion (n = 30), pepper (n = 27), tomato (n = 47), basil (n = 23), cabbage (n = 20), kale (n = 33).

Table 2
Mean (n = 6), soil parameters in Clean Soil Bank sediment (CSB S) and compost percentage admixtures (CSB 20%, CSB 33%, CSB 50%) used in study and control soil (CON). Mean values were taken from gardens 1, 2 and 3 directly after mixing in June 2015.

Soil Type	Soil Agronomic Parameter					
	pH	TDS (mg kg^{-1})	OM (%)	C/N	SOC (mg kg^{-1})	Total N (mg kg^{-1})
CON	8.0	146.2	4.5	20.0	2.9	0.1
CSB 20%	8.0	110.0	2.4	14.6	1.3	0.09
CSB 33%	8.1	119.1	3.4	13.2	1.9	0.1
CSB 50%	7.8	284.2	9.6	13.2	4.6	0.4

proximal and distal sources can contaminate newly emplaced clean soils (Clark, Hausladen, & Brabander, 2008; Laidlaw & Filippelli, 2008; Laidlaw, Zahran, Mielke, Taylor, & Filippelli, 2012; Laidlaw et al., 2016; Taylor, Mackay, Hudson-Edwards, & Holz, 2010; Zahran et al., 2013). This issue is particularly important for Garden 3, where adjacent soils contained high Pb and As (Table 1). The other two garden sites were located near homes constructed in the early part of the 20th century, as well as near elevated subway infrastructure, which may contain Pb paint and contribute to dust deposition (Caravanos, Weiss, Blaise, & Jaeger, 2006; Weiss, Caravanos, Blaise, & Jaeger, 2006; Young, Heeraman, Sirin, & Ashbaugh, 2002).

The lack of measurable recontamination in this study was likely due to a number of factors including mulch coverage surrounding the beds, which limits proximal soil movement (i.e., resuspension or tracking), as well as to the limited time frame of sampling (Binns et al., 2004). If mulch is acting as a filter for contaminant deposition, increasing concentrations may be evident over time. However, as mulch breaks down over time, the decomposing organic matter may alter metal speciation and bioavailability (Beesley & Dickinson, 2011; Schroth, Bostick, Kaste, & Friedland, 2008). A number of anthropogenic and climatic factors are involved in resuspension and deposition of contaminated soils, which is an ongoing phenomenon in need of further investigation (Del Rio-Salas et al., 2012; Pingitore, Clague, Amaya, Maciejewska, & Reynoso, 2009; Zheng, Shotyk, Krachler, & Fisher, 2007). Distal source contamination may also occur for these soils over time, and beds will be continually monitored.

While the manufactured soils contain extremely low levels of contamination, it was nonetheless important to analyze the safety of the produce to see if either contaminants in compost or the surrounding environment affected crops (Li et al., 2012; MacKinnon et al., 2011; Uzu et al., 2010; Wiseman, Zereini, & Püttmann, 2013). The crops grown in each of the manufactured soils contained negligible concentrations of contaminants and were safe for consumption (Fig. 2). Low Pb concentrations associated with basil and kale were strongly correlated with Al concentrations ($R^2 = 0.77$, $p < 0.001$, and $R^2 = 0.2$, $p = 0.02$, respectively). This finding suggests that the dominant source of Pb on these crops was surficial contamination from dust or entrained soil particles (McBride et al., 2014). While the adhered particles are difficult to wash off completely, the levels of contaminants found on vegetable tissues did not present significant risks (Attanayake et al., 2014). Controlling dust and splash with mulching around crops can minimize adhered soil particles (Brown et al., 2016). Adding compost to beds can also lead to greater aggregate stability which decreases dust and splash in addition to reducing contaminant phyto- and bioavailability (Henry et al., 2015).

4.2. Evaluating manufactured soils

Even during their initial year of formation, the CSB-compost mixtures supported a range of crop types and exhibited a range of soil parameters comparable to the purchased control topsoil. The soil parameters evaluated (Table 2) show appropriate physical and chemical properties for plant growth. The harvest weights suggest that with at least 33% compost in volume, the constructed soils produced comparable or greater yields than commercially available topsoil commonly used by urban community gardeners (Fig. 3). Adequate organic matter levels are needed for a range of soil physical, chemical, and agronomic properties. However, adding organic amendments can

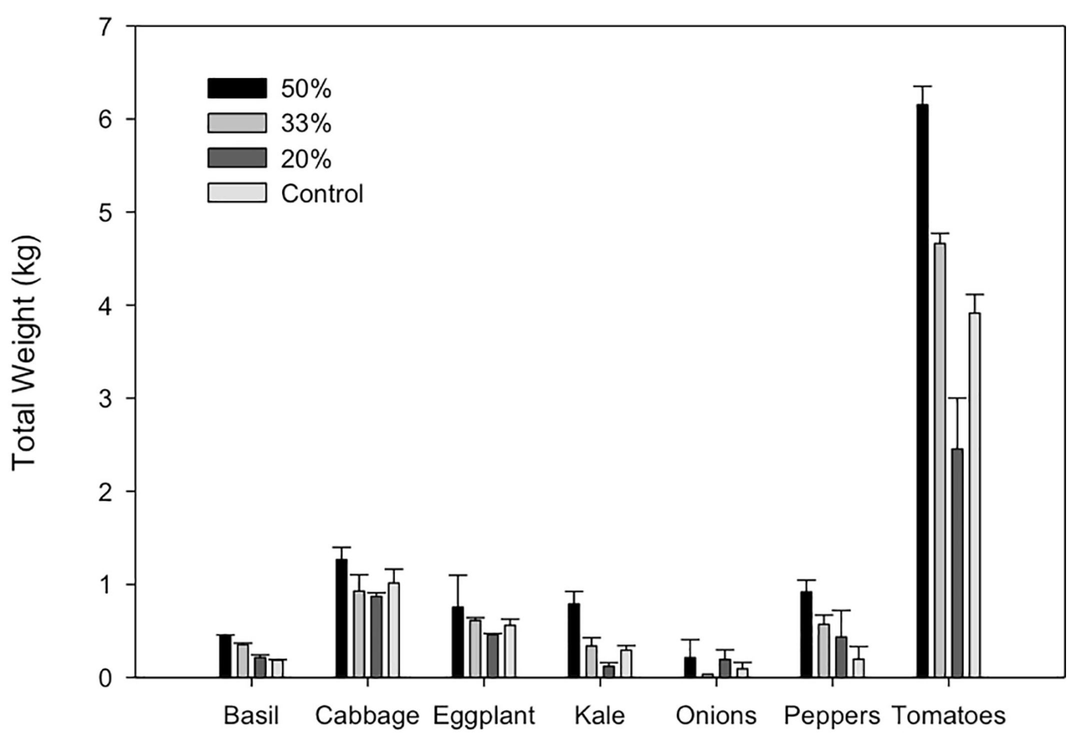

Fig. 4. Mean ± SE of crop yield (kg) in fresh weight (f.w.). Values are mean of CSB compost admixture beds (20%, 33%, 50%) and control soils from gardens 1 and 2.

increase cost and potentially increase contaminant concentrations (Smith, 2009). The results of this study suggest that the CSB sediments requires an addition of 33–50% compost by volume in order to provide adequate yield while minimizing cost and contaminant concentrations. Additional studies with other sediment and compost types are needed to further investigate these initial findings.

While the agronomic potential of the constructed soils were evaluated by their ability to support plant growth, there are other ways to assess soil quality, especially for engineered soils. For example, Sere et al. (2010) constructed soils and evaluated profile development, structure and aggregation, water movement and chemical weathering over a 3-year period. Soil health can be evaluated by the USDA-NRCS Soil Management and Assessment Framework (Andrews, Karlen, & Cambardella, 2004), and Cornell University's Comprehensive Assessment of Soil Health (Schindelbeck et al., 2008), which both include a variety of soil biological, chemical and physical parameters. There is currently no agreed upon framework for evaluating soil health in an urban context, particularly for newly constructed soils and urban agriculture. Our approach examined agricultural productivity and contamination over time, which should be included as important criteria when evaluating constructed soils in urban areas.

4.3. Utilizing waste materials for beneficial reuse

It is important to note that the CSB sediment and compost mixtures are constructed from materials that might otherwise enter landfills. There is a large volume of these or similar materials available in NYC and other cities. Over its first five years of operation, the CSB has transferred 4.2×10^5 tons of native sediment (Walsh et al., 2018). In addition to recycling sediment, the CSB has lowered costs of sediment management, reduced truck transport and diesel fuel consumption and lowered greenhouse gas emissions (Walsh et al., 2018). These environmental amenities are directly aligned with sustainability planning in NYC, which calls for reductions in greenhouse gas emissions and solid waste disposal, increased collection and reuse of organic materials, brownfield remediation, creation of additional community gardens and urban farms, and improved food access, affordability and quality (One NYC, 2017).

Composting initiatives in NYC have greatly expanded, both under the jurisdiction of the Department of Sanitation's (DSNY) NYC Compost Project, and through commercial and smaller composting facilities, as a key component of One NYC. In 2013, NYC disposed of 3.3 million tons of waste, 31% of which (1.023 million tons) was compostable organics (DSNY, 2013). In 2014, DSNY composted 892 tons of residential organics (DSNY, 2014). These initiatives are keeping food and yard waste out of landfills, but in order for the composts to work most effectively as growing media, an inorganic matrix is desired (Sloan et al., 2012). CSB sediments are ideal candidates. Constructing urban soils from these materials is consistent with systems-based approaches for social-ecological urban planning that also support ancillary urban ecosystem services (Bai et al., 2016; Ferris, Norman, & Sempik, 2001; McPhearson et al., 2016).

The 4.2×10^5 tons of native sediment that have already been reused locally in the CSB would enable coverage of all NYC gardens within slightly more than one year (Walsh et al., 2018). This calculated CSB volume accounts for only a small percentage of the total quantity of clean sediments generated in NYC. Economic constraints, limited facilities for storing and mixing soils, and the issues of small streets and fenced gardens contribute to the challenges of realizing the full potential of the CSB to construct soils on a large scale. These impediments are not insurmountable, and it is important to effectively address these issues so that the CSB can promote sustainable development and environmental and food justice (Horst, McClintock, & Hoey, 2017).

5. Conclusion

The use of CSB sediments and compost in this study effectively diverted waste materials from landfills and demonstrated their safe and effective use as manufactured topsoil. Composts, which must be mixed with CSB sediments to facilitate plant production, can be a source of contamination and must be carefully screened before use. Once placed in beds, contaminant concentrations in CSB sediment and compost mixtures did not change significantly over the first year. This indicates that environmental factors such as resuspension of surrounding soils and dusts had a negligible impact on contaminant concentrations in the soils and produce over this limited time period. These beds will be monitored over time for soil development and potential contamination from resuspended soils and dusts. The crop yields from beds containing at least 33% compost by volume were comparable to the commercial control topsoil. Both the yield values and soil parameters show that even in their first year of formation, these constructed soils were productive and comparable to topsoil otherwise available to community gardeners.

Clean soil is needed to mitigate exposure to contaminants and promote urban agriculture. Our findings suggest that CSB sediments mixed with urban composts have the capacity to begin to meet this need in NYC. However, creating these soils does not automatically guarantee that they benefit those most at risk to contaminant exposure and most in need of affordable healthy produce. Moving forward, the Clean Soil Bank presents a unique opportunity to develop urban social-ecological systems that connect city agencies, academic researchers, and local organizations to support urban gardening and environmental and food justice.

Acknowledgments

This manuscript is dedicated to the life and memory of Stanley Jones, whose kindness and commitment to gardening was vital for his community throughout his entire life of 84 years. This study could not have occurred without the generous support of Stanley and numerous other gardeners and collaborators. The authors would like to thank gardeners Katherine Bryant, Yolanda Belcher, Rochelle Sanders, Lakecia Davis-Flueck, Cheryl John, Deborah Greig, Kendra Ellis, David Vigil, and the entire community of East New York Farms!. GreenThumb was instrumental for this work, particularly the efforts of Shawn Spencer, Rasheed Hislop, Isak Mendes, Nancy Kohn, Carlos Martinez, and Bill LoSasso. We also want to thank the Brooklyn Queens Land Trust's Demetrice Mills for garden space and ongoing support. This research was also made possible by the Gowanus Canal Conservancy's Richard Kampf and Natasia Sidarta who facilitated the donation of their high quality compost. Many current and past staff members at the Mayor's Office of Environmental Remediation have created and continually manage the Clean Soil Bank, and we want to thank Shana Holberton, Samantha Morris, Noel Anderson, Kate Glass, and Taylor Hard, among others, for their hard work. Special thanks are given to Brooklyn College students and researchers Hermine Huot, Danielle Wagner, Jan Mun, Michael Grinshtein, Igor Bronz, Norma Sutton, Tamar Saimbert, J.D. Rachid, Lisa Bloodgood, Shruti Singh, Sophia Khoja, LiLin Liu, Zainab Salahudin, Zenab Jamil, Marzana Rafa, Jasleen Kaur, and Anna Minsky, whose volunteer time and efforts made this study a reality. We would also like to thank two anonymous reviewers for improving the manuscript with their constsructive feedback. Sondra Perl, Elaine Carberry, and Elizabeth-Ann Tierney provided manuscript edits and support for the entire research process, which has been continually and collaboratively constructed.

References

Aelion, C. M., Davis, H. T., Lawson, A. B., Cai, B., & McDermott, S. (2013). Associations between soil lead concentrations and populations by race/ethnicity and income-to-

poverty ratio in urban and rural areas. *Environmental Geochemistry and Health, 35*(1), 1–12. http://dx.doi.org/10.1007/s10653-012-9472-0.
Alaimo, K., Packnett, E., Miles, R. A., & Kruger, D. J. (2008). Fruit and vegetable intake among urban community gardeners. *Journal of Nutrition Education and Behavior, 40*(2), 94–101. http://dx.doi.org/10.1016/j.jneb.2006.12.003.
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. *Environmental Pollution, 144*(3), 736–745. http://dx.doi.org/10.1016/j.envpol.2006.03.001.
Alloway, B. J. (Ed.). (2010). *Heavy metals in soils*. London: Blackie Academic and Professional.
Andrews, S. S., Karlen, D. L., & Cambardella, C. A. (2004). The soil management assessment framework. *Soil Science Society of America Journal, 68*(6), 1945–1962. http://dx.doi.org/10.2136/sssaj2004.1945.
Angotti, T. (2015). Urban agriculture: Long-term strategy or impossible dream?: Lessons from Prospect Farm in Brooklyn, New York. *Public Health, 129*(4), 336–341. http://dx.doi.org/10.1016/j.puhe.2014.12.008.
Aptekar, S. (2015). Visions of public space: Reproducing and resisting social hierarchies in a community garden. *Sociological Forum, 30*(1), 209–227. http://dx.doi.org/10.1111/socf.12152.
Armstrong, D. (2000). A survey of community gardens in upstate New York: Implications for health promotion and community development. *Health & Place, 6*(4), 319–327. http://dx.doi.org/10.1016/S1353-8292(00)00013-7.
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. *Journal of Environmental Quality, 43*(2), 475–487. http://dx.doi.org/10.2134/jeq2013.07.0273.
Bai, X., Surveyer, A., Elmqvist, T., Gatzweiler, F. W., Güneralp, B., Parnell, S., ... Webb, R. (2016). Defining and advancing a systems approach for sustainable cities. *Current Opinion in Environmental Sustainability, 23*, 69–78. http://dx.doi.org/10.1016/j.cosust.2016.11.010.
Beesley, L., & Dickinson, N. (2011). Carbon and trace element fluxes in the pore water of an urban soil following greenwaste compost, woody and biochar amendments, inoculated with the earthworm Lumbricus terrestris. *Soil Biology and Biochemistry, 43*(1), 188–196. http://dx.doi.org/10.1016/j.soilbio.2010.09.035.
Biasioli, M., Grcman, H., Kralj, T., Madrid, F., Diaz-Barrientos, E., & Ajmone- Marsan, F. (2007). Potentially toxic elements contamination in urban soils: A comparison of three European cities. *Environmental Quality, 36*, 70–79.
Binns, H. J., Gray, K. A., Chen, T., Finster, M. E., Peneff, N., Schaefer, P., ... Dunlap, B. (2004). Evaluation of landscape coverings to reduce soil lead hazards in urban residential yards: The Safer Yards Project. *Environmental Research, 96*, 127–138. http://dx.doi.org/10.1016/j.envres.2004.02.010.
Blair, D., Giesecke, C. C., & Sherman, S. (1991). A dietary, social and economic evaluation of the Philadelphia urban gardening project. *Journal of Nutrition Education, 23*, 161–167.
Brady, N. C., & Weil, R. R. (2017). *The nature and properties of soils* (15th ed.). Boston, MA: Pearson.
Brandon, D.L., & Price, R.A., (2007). Summary of available guidance and best practices for determining suitability of dredged material for beneficial uses. USEPA ERDC/EL TR-O7-27.
Brose, D. A., Hundal, L. S., Oladeji, O. O., Kumar, K., Granato, T. C., Cox, A., & Abedin, Z. (2016). Greening a steel mill slag brownfield with biosolids and sediments: A case study. *Journal of Environmental Quality, 45*, 53–61.
Brown, S. L., Chaney, R. L., & Hettiarachchi, G. M. (2016). Lead in urban soils: A real or perceived concern for urban agriculture? *J Environ Qual, 45*, 26–36. http://dx.doi.org/10.2134/jeq2015.07.0376.
Brown, S., Kurtz, K., Bary, A., & Cogger, C. (2011). Quantifying benefits associated with land application of organic residuals in Washington state. *Environmental Science and Technology, 45*(17), 7451–7458. http://pubs.acs.org/doi/abs/10.1021/es2010418.
Caravanos, J., Weiss, A. L., Blaise, M. J., & Jaeger, R. J. (2006). A survey of spatially distributed exterior dust lead loadings in New York City. *Environmental Research, 100*(2), 165–172. http://dx.doi.org/10.1016/j.envres.2005.05.001.
Caspersen, C. J., Bloemberg, M., Saris, W. H. M., Merritt, R. K., & Kromhout, D. (1991). The prevalence of selected physical activities and their relation with coronary heart disease risk factors in elderly men: The Zutphen Study, 1985. *American Journal of Epidemiology, 133*, 1078–1092.
Cheng, Z., Lee, L., Dayan, S., Grinshtein, M., & Shaw, R. (2011). Speciation of heavy metals in garden soils: Evidences from selective and sequential chemical leaching. *Journal of Soils and Sediments, 11*(4), 628. http://dx.doi.org/10.1007/s11368-011-0351-6.
Cheng, Z., Paltseva, A., Li, I., Morin, T., Huot, H., Egendorf, S., ... Shaw, S. (2015). Trace metal contamination in New York City garden soils. *Soil Science, 180*, 167–174. http://dx.doi.org/10.1097/ss.0000000000000126.
Clark, H. F., Hausladen, D. M., & Brabander, D. J. (2008). Urban gardens: Lead exposure, recontamination mechanisms, and implications for remediation design. *Environmental Research, 107*, 312–319. http://dx.doi.org/10.1016/j.envres.2008.03.003.
Darmody, R. G., & Marlin, J. C. (2002). Sediments and sediment-derived soils in Illinois: Pedological and agronomic assessment. *Environmental Monitoring Assessment, 77*, 209–227.
Darmody, R. G., Marlin, J. C., Talbott, J., Green, R. A., Brewer, E. F., & Stohr, C. (2004). Dredged Illinois River sediments. *Journal of Environmental Quality, 33*, 458–464.
Deeb, M., Grimaldi, M., Lerch, T. Z., Pando, A., Gigon, A., & Blouin, M. (2016). Interactions between organisms and parent materials of a constructed technosol shape its hydrostructural properties. *Soil, 2*, 163–174.
Deeb, M., Grimaldi, M., Lerch, T. Z., Pando, A., Podwojewski, P., & Blouin, M. (2016). Influence of organic matter content on hydro-structural properties of constructed Technosols. *Pedosphere, 26*, 486–498.
Del Rio-Salas, R., Ruiz, J., De la O-Villanueva, M., Valencia-Moreno, M., Moreno-Rodríguez, V., Gómez-Alvarez, A., ... Meza-Figueroa, D. (2012). Tracing geogenic and anthropogenic sources in urban dusts: Insights from lead isotopes. *Atmospheric Environment, 60*, 202–210. http://dx.doi.org/10.1016/j.atmosenv.2012.06.061.
Delbecque, N., & Verdoodt, A. (2016). Spatial patterns of heavy metal contamination by urbanization. *Journal of Environmental Quality, 45*(1), 9–17. http://dx.doi.org/10.2134/jeq2014.11.0508.
DSNY (2013). Waste characterization study. Available at: < http://www1.nyc.gov/assets/dsny/docs/2013-Waste-Characterization-Study.pdf > (Accessed 21.01.18).
DSNY (2014). Community composting report. Available at: < http://www1.nyc.gov/assets/dsny/docs/about_2014-community-composting- report-LL77_0815.pdf > (Accessed 21.01.18).
EC (2006). Commission regulation (EC) no 1881/2006 of 19 December 2006 setting maximum levels for certain contaminants in foodstuffs. *Official Journal of the European Union, 364*, 06–24.
Eizenberg, E. (2012). *From the ground up: Community gardens in New York City and the politics of spatial transformation.* Vermont: Ashgate.
Epstein, E., Chaney, R. L., Henry, C., & Logan, T. J. (1992). Trace elements in municipal solid waste compost. *Biomass and Bioenergy, 3*(3), 227–238. http://dx.doi.org/10.1016/0961-9534(92)90028-O.
Epstein, E. E., Taylor, J. M., & Chaney, R. L. (1976). Effects of sewage sludge and compost applied to soil on some soil physical and chemical properties. *Journal of Environmental Quality, 5*, 422–426.
Fabrigoule, C., Letenneur, L., Dartigues, J. F., Zarrouk, M., Commenges, D., & Barberger-Gateau, P. (1995). Social and leisure activities and risk of dementia: A prospective longitudinal study. *Journal of the American Geriatrics Society, 43*, 485–490 < https://onlinelibrary-wiley-com.ezproxy.gc.cuny.edu/doi/full/10.1111/j.1532-5415.1995.tb06093.x > .
Farrell, M., & Jones, D. L. (2009). Heavy metal contamination of a mixed waste compost: Metal speciation and fate. *Bioresource Technology, 100*(19), 4423–4432. http://dx.doi.org/10.1016/j.biortech.2009.04.023.
Ferris, J., Norman, C., & Sempik, J. (2001). People, land and sustainability: Community gardens and the social dimension of sustainable development. *Social Policy & Administration, 35*(5), 559.
Filippelli, G. M., & Laidlaw, M. A. S. (2010). The elephant in the playground: Confronting lead-contaminated soils as an important source of lead burdens to urban populations. *Perspectives in Biology and Medicine, 53*(1), 31–45. http://dx.doi.org/10.1353/pbm.0.0136.
Finster, M. E., Gray, K. A., & Binns, H. J. (2004). Lead levels of edibles grown in contaminated residential soils: A field survey. *Science of the Total Environment, 320*(2–3), 245–257. http://dx.doi.org/10.1016/j.scitotenv.2003.08.009.
Fitzstevens, M. G., Sharp, R. M., & Brabander, D. J. (2017). Biogeochemical characterization of municipal compost to support urban agriculture and limit childhood lead exposure from resuspended urban soils. *Elem Sci Anth, 5*. http://dx.doi.org/10.1525/elementa.238.
Gittleman, M., Farmer, C. J., Kremer, P., & McPhearson, T. (2016). Estimating stormwater runoff for community gardens in New York City. *Urban Ecosystems, 19*(2).
Goddard, M. A., Dougill, A. J., & Benton, T. G. (2010). Scaling up from gardens: Biodiversity conservation in urban environments. *Trends in Ecology & Evolution, 25*(2), 90–98. http://dx.doi.org/10.1016/j.tree.2009.07.016.
Gustavsson, N., Bølviken, B., Smith, D.B., Severson, R.C. (2001). Geochemical landscapes of the conterminous United States—New map presentations for 22 elements. Denver CO:U.S. Geological Survey Professional Paper 1648.
Hargreaves, J. C., Adl, M. S., & Warman, P. R. (2008). A review of the use of composted municipal solid waste in agriculture. *Agriculture, Ecosystems & Environment, 123*(1), 1–14. http://dx.doi.org/10.1016/j.agee.2007.07.004.
Henry, H., Naujokas, M. F., Attanayake, C., Basta, N. T., Cheng, Z., Hettiarachchi, G. M., ... Scheckel, K. G. (2015). Bioavailability-based in situ remediation to meet future lead (Pb) standards in urban soils and gardens. *Environmental Science & Technology, 49*, 8948–8958. http://dx.doi.org/10.1021/acs.est.5b01693.
Horst, M., McClintock, N., & Hoey, L. (2017). The Intersection of planning, urban agriculture, and food justice: A review of the literature. *Journal of the American Planning Association, 83*(3), 277–295. http://dx.doi.org/10.1080/01944363.2017.1322914.
Hung, Y. (2004). East New York farms: Youth participation in community development and urban agriculture. *Children, Youth and Environments, 14*(1), 56–85.
Kaplan, R. (1973). Some psychological benefits of gardening. *Environment and Behavior, 5*, 145–162.
Kelling, K. A., Peterson, A. E., & Walsh, L. M. (1977). Effect of wastewater sludge on soil moisture relationships and surface runoff. *Journal of the Water Pollution Control Federation, 49*, 1698–1703.
Kelly, J., & Thornton, I. (1996). Urban geochemistry: A study of the influence of anthropogenic activity on the heavy metal content of soils in traditionally industrial and non-industrial areas of Britain. *Applied Geochemistry, 11*, 363–370.
Kupper, T., Bürge, D., Bachmann, H. J., Güsewell, S., & Mayer, J. (2014). Heavy metals in source-separated compost and digestates. *Waste Management, 34*(5), 867–874. http://dx.doi.org/10.1016/j.wasman.2014.02.007.
Laidlaw, M. A. S., & Filippelli, G. M. (2008). Resuspension of urban soils as a persistent source of lead poisoning in children: A review and new directions. *Applied Geochemistry, 23*(8), 2021–2039. http://dx.doi.org/10.1016/j.apgeochem.2008.05.009.
Laidlaw, M. A. S., Filippelli, G. M., Brown, S., Paz-Ferreiro, J., Reichman, S. M., Netherway, P., ... Mielke, H. W. (2017). Case studies and evidence-based approaches to addressing urban soil lead contamination. *Applied Geochemistry, 83*, 14–30.
Laidlaw, M. A. S., Filippelli, G. M., Sadler, R. C., Gonzales, C. R., Ball, A. S., & Mielke, H. W. (2016). Children's blood lead seasonality in Flint, Michigan (USA), and soil-

sourced lead hazard risks. *International Journal of Environmental Research and Public Health, 13*(4), http://dx.doi.org/10.3390/ijerph13040358 358–358.
Laidlaw, M. A. S., Zahran, S., Mielke, H. W., Taylor, M. P., & Filippelli, G. M. (2012). Resuspension of lead contaminated urban soil as a dominant source of atmospheric lead in Birmingham, Chicago, Detroit and Pittsburgh, USA. *Atmospheric Environment, 49*, 302–310. http://dx.doi.org/10.1016/j.atmosenv.2011.11.030.
Lembke, W. D., Mitchell, J. K., Fehrenbacher, J. B., Barcelona, M. J., Garske, E. E., & Heffelfinger, S. R. (1983). Dewatering dredged sediment for agriculture. *Transactions of the American Society of Agricultural Engineers, 26*, 808–813.
Li, F.-L., Liu, C.-Q., Yang, Y.-G., Bi, X.-Y., Liu, T.-Z., & Zhao, Z.-Q. (2012). Natural and anthropogenic lead in soils and vegetables around Guiyang city, southwest China: A Pb isotopic approach. *Science of the Total Environment, 431*, 339–347. http://dx.doi.org/10.1016/j.scitotenv.2012.05.040.
Lin, B. B., Philpott, S. M., & Jha, S. (2015). The future of urban agriculture and biodiversity-ecosystem services: Challenges and next steps. *Basic and Applied Ecology, 16*(3), 189–201. http://dx.doi.org/10.1016/j.baae.2015.01.005.
Litt, J. S., Soobader, M.-J., Turbin, M. S., Hale, J. W., Buchenau, M., & Marshall, J. A. (2011). The influence of social involvement, neighborhood aesthetics, and community garden participation on fruit and vegetable consumption. *American Journal of Public Health, 101*(8), 1466–1473. http://dx.doi.org/10.2105/AJPH.2010.300111.
MacKinnon, G., MacKenzie, A. B., Cook, G. T., Pulford, I. D., Duncan, H. J., & Scott, E. M. (2011). Spatial and temporal variations in Pb concentrations and isotopic composition in road dust, farmland soil and vegetation in proximity to roads since cessation of use of leaded petrol in the UK. *Science of the Total Environment, 409*(23), 5010–5019. http://dx.doi.org/10.1016/j.scitotenv.2011.08.010.
Magnus, K., Matroos, A., & Strackee, J. (1979). Walking, cycling, or gardening, with or without seasonal interruption, in relation to acute coronary events. *American Journal of Epidemiology, 110*, 724–733.
Marquez-Bravo, L. G., Briggs, D., Shayler, H., McBride, M., Lopp, D., Stone, E., ... Spliethoff, H. M. (2016). Concentrations of polycyclic aromatic hydrocarbons in New York City community garden soils: Potential sources and influential factors. *Environmental Toxicology and Chemistry, 35*(2), 357–367. http://dx.doi.org/10.1002/etc.3215.
McBride, M. B., Shayler, H. A., Spliethoff, H. M., Mitchell, R. G., Marquez-Bravo, L. G., Ferenz, G. S., ... Bachman, S. (2014). Concentrations of lead, cadmium and barium in urban garden-grown vegetables: The impact of soil variables. *Environmental Pollution, 194*, 254–261. http://dx.doi.org/10.1016/j.envpol.2014.07.036.
McClintock, N. (2015). A critical physical geography of urban soil contamination. *Urban Studies and Planning Faculty Publications and Presentations*. http://dx.doi.org/10.1016/j.geoforum.2015.07.010.
McCormack, L. A., Laska, M. N., Larson, N. I., & Story, M. (2010). Review of the nutritional implications of farmers' markets and community gardens: A call for evaluation and research efforts. *Journal of the American Dietetic Association, 110*(3), 399–408. http://dx.doi.org/10.1016/j.jada.2009.11.023.
McGeehan, S. L., & Naylor, D. V. (1988). Automated instrumental analysis of carbon and nitrogen in plant and soil samples. *Communications in Soil Science and Plant Analysis, 19*(4), 493–505. http://dx.doi.org/10.1080/00103628809367953.
McPhearson, T., Kremer, P., & Hamstead, Z. A. (2013). Mapping ecosystem services in New York City: Applying a social–ecological approach in urban vacant land. *Ecosystem Services, 5*, 11–26. http://dx.doi.org/10.1016/j.ecoser.2013.06.005.
McPhearson, T., Pickett, S. T. A., Grimm, N. B., Niemelä, J., Alberti, M., Elmqvist, T., ... Qureshi, S. (2016). Advancing urban ecology toward a science of cities. *BioScience, 66*(3), 198–212. http://dx.doi.org/10.1093/biosci/biw002.
Meenar, M. R., & Hoover, B. M. (2016). Community food security via urban agriculture: Understanding people, place, economy, and accessibility from a food justice perspective. *Journal of Agriculture, Food Systems, and Community Development, 3*(1), 143–160. http://dx.doi.org/10.5304/jafscd.2012.031.013.
Mielke, H. W. (2015). Soils and health: Closing the soil knowledge gap. *Soil Horizons, 56*. http://dx.doi.org/10.2136/sh2015-56-4-gc.
Mielke, H. W. (2016). Nature and extent of metal-contaminated soils in urban environments (keynote talk). *Environmental Geochemistry and Health, 38*(4), 987–999. http://dx.doi.org/10.1007/s10653-016-9792-6.
Mielke, H. W., & Reagan, P. (1998). Soil is an important pathway of human lead exposure. *Environmental Health Perspectives, 106*, 217–229.
Mitchell, R. G., Spliethoff, H. M., Ribaudo, L. N., Lopp, D. M., Shayler, H. A., Marquez-Bravo, L. G., ... McBride, M. B. (2014). Lead (Pb) and other metals in New York City community garden soils: Factors influencing contaminant distributions. *Environmental Pollution, 187*, 162–169. http://dx.doi.org/10.1016/j.envpol.2014.01.007.
Nabulo, G., Oryem-Origa, H., & Diamond, M. (2006). Assessment of lead, cadmium, and zinc contamination of roadside soils, surface films, and vegetables in Kampala City, Uganda. *Environmental Research, 101*(1), 42–52. http://dx.doi.org/10.1016/j.envres.2005.12.016.
NIST, (2013). National Institute of Standards and Technology, Standard Reference Material 2587. Trace elements in soil containing lead from paint. < https://www-s.nist.gov/srmors/certificates/2587.pdf > .
NIST, (2017). National Institute of Standards and Technology, Standard Reference Material 2586. Trace elements in soil containing lead from paint. < https://www-s.nist.gov/srmors/certificates/2586.pdf > .
NYSDEC, (2006). New York State Department of Environmental Conservation 6 NYCRR Part 375-Environmental Remediation Programs.
Okvat, H. A., & Zautra, A. J. (2011). Community gardening: A parsimonious path to individual, community, and environmental resilience. *American Journal of Community Psychology, 47*(3–4), 374–387. http://dx.doi.org/10.1007/s10464-010-9404-z.
One NYC, (2017). < https://onenyc.cityofnewyork.us/about/ > .
Paradelo, R., & Barral, M. T. (2013). Influence of organic matter and texture on the compactability of Technosols. *Catena, 110*, 95–99.
Pingitore, N. E., Clague, J. W., Amaya, M. A., Maciejewska, B., & Reynoso, J. J. (2009). Urban airborne lead: X-ray absorption spectroscopy establishes soil as dominant source. *PLoS One, 4*(4), e5019. http://dx.doi.org/10.1371/journal.pone.0005019.
R Core Team, (2014). R: A Language and Environment for Statistical Computing.
Ramírez, M. M. (2015). The elusive inclusive: Black food geographies and racialized food spaces. *Antipode, 47*(3), 748–769. http://dx.doi.org/10.1111/anti.12131.
Reeves, D. W. (1997). The role of soil organic matter in maintaining soil quality in continuous cropping systems. *Soil & Tillage Research, 43*, 131–167.
Reynolds, K. (2015). Disparity despite diversity: Social injustice in New York City's urban agriculture system. *Antipode, 47*(1), 240–259. http://dx.doi.org/10.1111/anti.12098.
Rokia, S., Sere, G., Schwartz, C., Deeb, M., Fournier, F., Nehls, T., ... Vidal-Beaudet, L. (2014). Modelling agronomic properties of Technosols constructed with urban wastes. *Waste Management, 34*, 2155–2162.
Saldivar-Tanaka, L., & Krasny, M. E. (2004). Culturing community development, neighborhood open space, and civic agriculture: The case of Latino community gardens in New York City. *Agriculture and Human Values, 21*(4), 399–412. http://dx.doi.org/10.1023/B:AHUM.0000047207.57128.a5.
Samsøe-Petersen, L., Larsen, E. H., Larsen, P. B., & Bruun, P. (2002). Uptake of trace elements and PAHs by fruit and vegetables from contaminated soils. *Environmental Science & Technology, 36*(14), 3057–3063. http://dx.doi.org/10.1021/es015691t.
Sbicca, J., & Myers, J. S. (2017). Food justice racial projects: Fighting racial neoliberalism from the Bay to the Big Apple. *Environmental Sociology, 3*(1), 30–41. http://dx.doi.org/10.1080/23251042.2016.1227229.
Schindelbeck, R. R., van Es, H. M., Abawi, G. S., Wolfe, D. W., Whitlow, T. L., Gugino, B. K., ... Moebius-Clune, B. N. (2008). Comprehensive assessment of soil quality for landscape and urban management. *Landscape and Urban Planning, 88*(2–4), 73–80. http://dx.doi.org/10.1016/j.landurbplan.2008.08.006.
Schreck, E., Foucault, Y., Sarret, G., Sobanska, S., Cécillon, L., Castrec-Rouelle, M., ... Dumat, C. (2012). Metal and metalloid foliar uptake by various plant species exposed to atmospheric industrial fallout: Mechanisms involved for lead. *Science of the Total Environment, 427*, 253–262. http://dx.doi.org/10.1016/j.scitotenv.2012.03.051.
Schroth, A. W., Bostick, B. C., Kaste, J. M., & Friedland, A. J. (2008). Lead sequestration and species redistribution during soil organic matter decomposition. *Environmental Science & Technology, 42*(10), 3627–3633. http://dx.doi.org/10.1021/es703002b.
Sere, G., Schwartz, C., Ouvrard, S., Renat, J. C., Watteau, F., Villemin, G., & Morel, J. L. (2010). Early pedogenic evolution of constructed Technosols. *Journal of Soils and Sediments, 10*, 1246–1254.
Sere, G., Schwartz, C., Ouvrard, S., Sauvage, C., Renat, J. C., & Morel, J. L. (2008). Soil construction: A step for ecological reclamation of derelict lands. *Journal of Soils and Sediments, 82*, 130–138.
Sharp, R. M., & Brabander, D. J. (2017). Lead (Pb) bioaccessibility and mobility assessment of urban soils and composts: Fingerprinting sources and refining risks to support urban agriculture. *GeoHealth*. http://dx.doi.org/10.1002/2017GH000093 2017GH000093.
Sloan, J. J., Ampim, P. A., Basta, N. T., & Scott, R. (2012). Addressing the need for soil blends and amendments for the highly modified urban landscape. *Soil Science Society of America Journal, 76*, 1133–1141.
Smith, S. R. (2009). A critical review of the bioavailability and impacts of heavy metals in municipal solid waste composts compared to sewage sludge. *Environment International, 35*(1), 142–156. http://dx.doi.org/10.1016/j.envint.2008.06.009.
Soil Survey Staff (2014). Kellogg soil survey laboratory methods manual. Soil survey investigations report no. 42, version 5.0. R. Burt and Soil Survey Staff (ed.). U.S. Department of Agriculture, Natural Resources Conservation Service.
Spliethoff, H. M., Mitchell, R. G., Shayler, H., Marquez-Bravo, L. G., Russell-Anelli, J., Ferenz, G., & McBride, M. (2016). Estimated lead (Pb) exposures for a population of urban community gardeners. *Environmental Geochemistry and Health, 38*(4), 955–971. http://dx.doi.org/10.1007/s10653-016-9790-8.
Taylor, M. P., Mackay, A. K., Hudson-Edwards, K. A., & Holz, E. (2010). Soil Cd, Cu, Pb and Zn contaminants around Mount Isa city, Queensland, Australia: Potential sources and risks to human health. *Applied Geochemistry, 25*(6), 841–855. http://dx.doi.org/10.1016/j.apgeochem.2010.03.003.
Twiss, J., Dickinson, J., Duma, S., Kleinman, T., Paulsen, H., & Rilveria, L. (2003). Community gardens: Lessons learned from California healthy cities and communities. *American Journal of Public Health, 93*(9), 1435.
USEPA. (1970). Clean Air Act (CAA). < https://www.epa.gov/laws-regulations/summary-clean-air-act > .
USEPA. (1978). Toxic Substances Control Act (TSCA): Chemical Substances Inventory. < http://www2.epa.gov/tsca-inventory/about-tsca-chemical-substance-inventory > .
USEPA. (1996). Method 3052: Microwave assisted acid digestion of siliceous and organically based matrices. < https://www.epa.gov/sites/production/files/2015- 12/documents/3052.pdf > .
USEPA. (1998). Method 6020A: Inductively coupled plasma - Mass Spectrometry. < https://www.epa.gov/sites/production/files/2015-07/documents/epa- 6020a.pdf > .
USEPA. (2007). Method 3051A: Microwave assisted acid digestion of sediments, sludges, soils, and oils. < https://www.epa.gov/sites/production/files/2015-12/documents/3051a.pdf > .
USEPA. (2014). Technical Review Workgroup Recommendations Regarding Gardening and Reducing Exposure to Lead-Contaminated Soils. OSWER 9200:2–142, US Environmental Protection Agency.
Uzu, G., Sobanska, S., Sarret, G., Muñoz, M., & Dumat, C. (2010). Foliar lead uptake by lettuce exposed to atmospheric fallouts. *Environmental Science & Technology, 44*(3), 1036–1042. http://dx.doi.org/10.1021/es902190u.
Wakefield, S., Yeudall, F., Taron, C., Reynolds, J., & Skinner, A. (2007). Growing urban

health: Community gardening in South-East Toronto. *Health Promotion International, 22*(2), 92–101. http://dx.doi.org/10.1093/heapro/dam001.

Walsh, D. C., Glass, K., Morris, S., Zhang, H., McRae, I., Anderson, N., ... Cheng, Z. (2018). Sediment exchange to mitigate pollutant exposure in urban soil. *Environmental Management, 214*, 354–361. http://dx.doi.org/10.1016/j.jenvman.2018.03.013.

Weiss, A. L., Caravanos, J., Blaise, M. J., & Jaeger, R. J. (2006). Distribution of lead in urban roadway grit and its association with elevated steel structures. *Chemosphere, 65*(10), 1762–1771. http://dx.doi.org/10.1016/j.chemosphere.2006.04.079.

White, M. M. (2011). Sisters of the Soil: Urban Gardening as Resistance in Detroit. *Race/Ethnicity: Multidisciplinary Global. Contexts, 5*(1), 13–28.

Wiseman, C. L. S., Zereini, F., & Püttmann, W. (2013). Traffic-related trace element fate and uptake by plants cultivated in roadside soils in Toronto, Canada. *Science of the Total Environment, 442*, 86–95. http://dx.doi.org/10.1016/j.scitotenv.2012.10.051.

Yadav, P., Duckworth, K., & Grewal, P. S. (2012). Habitat structure influences below ground biocontrol services: A comparison between urban gardens and vacant lots. *Landscape and Urban Planning, 104*(2), 238–244. http://dx.doi.org/10.1016/j.landurbplan.2011.10.018.

Young, T. M., Heeraman, D. A., Sirin, G., & Ashbaugh, L. L. (2002). Resuspension of soil as a source of airborne lead near industrial facilities and highways. *Environmental Science & Technology, 36*(11), 2484–2490. http://dx.doi.org/10.1021/es015609u.

Zahran, S., Laidlaw, M. A. S., McElmurry, S. P., Filippelli, G. M., & Taylor, M. (2013). Linking source and effect: Resuspended soil lead, air lead, and children's blood lead levels in Detroit, Michigan. *Environmental Science & Technology, 47*(6), 2839–2845. http://dx.doi.org/10.1021/es303854c.

Zar, J. H. (2010). *Biostatistical analysis* (5th ed.). New Jersey: Pearson Prentice Hall.

Zheng, J., Shotyk, W., Krachler, M., & Fisher, D. A. (2007). A 15,800-year record of atmospheric lead deposition on the Devon Island Ice Cap, Nunavut, Canada: Natural and anthropogenic enrichments, isotopic composition, and predominant sources. *Global Biogeochemical Cycles, 21*(2), http://dx.doi.org/10.1029/2006GB002897 GB2027.