GET THE LEAD OUT: EVALUATING THE INFLUENCE OF HEAVY METAL CONTAMINATED SOILS ON URBAN AGRICULTURE

DEPARTMENT OF ENVIRONMENTAL STUDIES

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ABSTRACT

In post-industrialized cities, soils are often contaminated with heavy metals due to legacies of industrial pollution. With the modern expansion of urban agriculture, ranging from community gardens to aquaponic systems, many practices may occur within marginalized contaminated soils. This study first works to identify existing literature that details heavy metal soil contamination in urban settings and the impacts it has on urban agriculture. The addition of organic soil amendments rather than traditional chemical fertilizer correlates with lower insect pest abundance while assisting in remediation of contaminants by lessening mobility and bioavailability of heavy metals within the soil. The experiment aspect of this study examines the effects of lead contaminated soils and how it affects tomato (*Solanum lycopersicum* var. ‘Moneymaker’) defenses and beet armyworm (*Spodoptera exigua)* growth and development. The results did not yield significance, stressing the need for additional research on insect pest and soil amendments in contaminated soils. In modern urban agriculture, there remains a large disconnect between scientific research and accessible information for the lay public to implement. The study includes a bulletin of accessible methods for contaminated soil remediation, utilizing strategies developed to help increase science communication.

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CHAPTER 1: URBAN SOILS & AGRICULTURE

Urban agriculture is increasing in popularity to combat food insecurity and malnutrition; however, many of areas of urban food production are also located in marginalized, contaminated soils due to years of industrial activities (Minca & Basta, 2013; Sharma et al., 2015). As urban settings continue to expand and redevelop lands within existing urban boundaries, urban legacies and heavy metal contamination will affect a greater range of regions. Clarke et al. (2015) found that anthropogenic heavy metal contamination was widespread and spatially variable across community gardens in Los Angeles, California. While the percent of US urban agriculture in contaminated soils is unknown, higher contamination levels will be observed closer to urban epicenters and busy roadways, however it is expected that the majority of urban sites will hold some amount of anthropogenic metal contamination (Sharma et al., 2015)

City environments are often closer to polluter sources, with common sources such as lead paint in residential communities, exhaust emissions close to roadways, or atmospheric deposition of lead at a site downwind from smelting (Clarke et al., 2015; Guilland et al., 2018; Kim et al., 2014; Minca & Basta, 2013). Concentrations of heavy metals have been found to increase with age and proximity to roadways, likely due to roadside pollution over time (Clarke et al., 2015). Heavy metals are unable to break down in the environment and thus continue to bioaccumulate without remediation. Heavy metal contaminants impact growers and consumers by entering the body through contaminated dust or the consumption of foods grown in the impacted soils (Kaiser et al., 2015a). As the world's population continues to increase, heavy metal pollution becomes a greater threat to food and environmental security due to continual environmental degradation and exponential growth of agricultural and industrial practices (Sarwar et al., 2017).

Heavy metal contamination largely occurred during the early 20th century in the United States, as industrialized cities incinerated great proportions of generated waste, depositing excessive amounts of trace metal contaminants aerially across urban soil (Paltseva, 2019). Between the 1880s and the 1970s, over 6,000 grams of lead was used in paint in the United States (McClintock, 2012). Residential neighborhoods that were built prior to the late 1970s may hold high levels of lead concentrated in the soil (McClintock, 2012). Additional lead contaminants include leaded gasoline, some pesticides (specifically Pb-based) and abandoned car batteries (Defoe et al., 2014). The expansive network of contamination sources in cities threaten urban agricultural and human health systems if not appropriately mitigated.

Heavy metal mobility and uptake in urban food crops poses substantial risk to organisms that feed on these plants (Zhou et al., 2012). Industrial activity and subsequent soil contamination can furthermore affect ecosystem functions, such as net primary productivity and predator-prey dynamics. Azmat et al. (2018) found that impacts of copper metal toxicity resulted in reduced growth rates of *Luffa acutangular* and spinach (*Spinacia oleracea*) plants along with dense growth of the cotton seed bug (*Oxycarenus hyalinipennis*), an insect herbivore, followed by degradation and chewing of the toxic plant. The survival and growth of insect herbivores heavily depend on dietary quality, specifically the ratios of protein: carbohydrates. Larval lepidopterans, for example typically suffer from reduced survival rates, longer developmental times and reduced pupal mass when faced with protein deficient diets (Lemoine & Shantz, 2016). Within species of host plants, individual plant quality is the main aspect of plant selection by herbivores. Plants in abiotic stress may contain a distorted C-N ratio due to the destruction of plant metabolism stemming from disturbances in soil biota, causing an increase of preference from plant-feeders (Azmat et al., 2018).

The centrality of ecosystem functions in agriculture and food production may impact urban gardens and food security when contamination is present in the environment, as many naturally occurring nutrients are beneficial to plant growth. Non-essential metals, such as lead (Pb), mercury, (Hg), and cadmium (Cd) have no known beneficial biological functions towards plant growth and can inhibit necessary biological processes by replacing essential metals or by altering plant stress regulatory functions (Sarwar et al., 2017). Lead (Pb) especially poses major health risks for inner city residents, targeting individuals continually exposed to open soil and consuming produce that may have remnant soil on its surface. Lead exposure is especially harmful for children, commonly entering bloodstreams through the inhalation or ingestion of soil, and can accumulate in bone tissue and cause permanent cognitive deficits (Sharp & Brabander, 2017).

Soil contamination and its influences on plants

Bioavailability, or the portion of a contaminant or resource able to be taken up by a plant, of heavy metals within the soil is an important factor to look at when analyzing the effects on plants and their ability to defend themselves from attack by herbivores or pathogens. Nickel, for instance, is readily taken up by plants and is highly mobile to easily transport between distant parts of the plant. Multiple, sometimes simultaneous, challenges and stresses reduce growth and yield in plants. When damage is inflicted via herbivory or pathogenesis, a plant may induce a resistance response to subsequent challenge (Bostock, 2005). Plants are able to utilize constitutive (always present) and induced defense (induced by wounding of a pest) mechanisms (Kessler & Baldwin, 2002). When a plant's growth is weakened, often by heavy metals and other contaminants in its growing medium, its defense mechanisms against pests are additionally reduced, in turn reducing crop yields.

Organic amendments added to contaminated soils may remediate some of the negative impacts of heavy metals, increasing the plant's ability to defend itself from other stressors. In conventional farming, high levels of soluble inorganic fertilizers infiltrate soils which can lead to leeching and plant stress due to instant access to a surplus of bioavailable nitrogen (Altieri & Nicholls, 2003). Soil organic matter is a critical component in both managed and natural ecosystems by maintaining soil structure and water-holding capacity, reduction in erosion, and providing organic substrate for nutrient release (Matson et al., 1997).

Altieri & Nicholls (2003) found that when crops are grown in good fertile soil—typically meaning higher levels of organic matter and active soil biology—they generally exhibit lower abundances of insect herbivores, likely due to the reduced nitrogen content within organic farming. While the use of inorganic and industrially produced fertilizers have been vital in increasing food production within the last half century, the biological and environmental consequences still remain in agroecosystems (Matson et al., 1997). Soil organic matter and organisms that process the availability of nutrients are substantially altered by the excess use of

N-based inorganic fertilizers. While N may offset low soil nutrient availabilities and increase production, yield, and quality of crops, added N can be lost from the systems through trace gases emitted into the atmosphere or as nitrate leeching from beneath the soil to the surface or groundwater (Matson et al., 1997).

Organic fertilizers work in the opposite manner by slowly releasing nutrients and is utilized in almost all strategies for contamination remediation. After adding organic compost, Liu et al. (2020) noted significant decreases of available Pb in soil and total Pb in roots and leaves of bok choy cabbage (*Brassica rapa* subsp. *Chinensis)* in a greenhouse experiment in China. The study found that organic soil amendments worked as effective methods to remediate heavy metal contamination in soil by altering mobility and bioavailability of contaminants. Farrell & Jones (2010) additionally found that the addition of organic amendments can accelerate natural remediation processes of soils, which naturally would take greater amounts of time due to the bioaccumulation of heavy metals in soil and their inability to break down.

Strategies for soil remediation

Plant defense mechanisms are critical in measuring the levels of damage a pest or pathogen may cause on an individual or group of surrounding plants. While plant hormones were originally recognized as regulators for growth and development, ongoing research is finding that the diverse group of plant hormones play pertinent roles in triggering the immune response (Pieterse et al., 2012). When an environment contributes different stressors, hormonal "cross talk" occurs between distinct hormone signal transduction pathways to determine the greatest threat to the individual plant. These hormones interact with either positive or negative correlations to combat the targeted stressor.

Within the plant defense network, salicylic acid (SA) and jasmonic acid (JA) are both recognized are major hormones. The SA-defensive pathway targets defense mechanisms against microbial biotrophic pathogens or other environmental stressors, including soil contamination (Pieterse et al., 2012). The JA-defensive pathway rapidly synthesizes an immune response upon herbivore damage (Kessler & Baldwin, 2002). Once the JA pathway is activated within a plant, similar JA-dependent responses may be triggered within distal, undamaged plant parts (Pieterse et al., 2012).

Due to JA defenses being typically targeted towards herbivorous insects and SA defenses to biotrophs, pathogens, and environmental stressors, the tradeoffs between the two hormones are important in determining how plants react to various stressors. The crosstalk between SA and JA-mediated responses is generally negative, meaning that the increases of one hormone's levels reduces the defense responses under control of the other (Glas et al., 2014). In nature, plants are simultaneously exposed to numerous stressors—both abiotic and biotic—along with the opposing effects of many other hormones.

Regarding high levels of heavy metal soil contamination, the JA-defensive pathways may become down regulated to account for the upregulation of SA-defenses to combat the environmental stress from the soil. This would result in lower plant defenses targeted towards the herbivory of the insect. As Altieri & Nicholls (2003) found, increased damage and growth of insect herbivores were found in crop plants containing N-fertilizer or synthetic soil amendments compared to organic amendments. While further research is required, this may be due to the upregulation of the SA-pathway, likewise downregulating JA-defenses. Using chemical fertilizers can alter the balance of available nutrition and amino acids in plants and excess use may create further nutrient imbalances, resulting in lowered resistance to insect pests (Altieri & Nicholls, 2003).

Through similar studies comparing fertilizer usage on soils and pest resistance by the crops, there appears to be a correlation worth studying between organic fertilization of soils and increased pest defense by the plants through induced plant hormones, also known as phytohormones (Chen et al, 2007; Lange et al, 2019; Rowen et al, 2019). The dissemination of this research and future findings regarding the importance of fertilizer choice, contamination, and plant defenses are especially pertinent in vacant lot agriculture where land management revolves around the presence of contaminants and how to safely mitigate their effects on human and crop health.

Urban garden practices for remediation

Concerning the quality control of commercial products, numerous systems are in place to ensure healthy produce while there are seemingly none regarding homegrown or community-based produce. Increasing consumptive trends promote cultivation in private gardens, community and school gardens, therefore increasing the risk of exposure to metals and toxic compounds (Augustsson et al., 2018). However, the lack of information flow between agricultural researchers and individuals working with or around contaminated soils influences the health impacts by individual knowledge.

The three main types of remediation strategies for mitigating contaminated soils include digging and hauling away contaminated soils to be replaced with cleaner soil (most disruptive and economically demanding method); leaving the contaminated soil in place and cover with a barrier to reduce exposure risk; and to treat soil in place with amendments that chemically change Pb compounds to become less bioavailable (Henry et al., 2015). Sharp & Brabender (2017) note that planting crops in raised beds containing low-Pb compost or mixing and diluting contaminated soil with compost as popular and applicable methods for urban gardeners to lessen heavy metal contaminant exposure. While these soil management strategies work to properly reduce garden soil Pb concentrations below neighborhood averages, Pb concentrations must be low enough to prevent negative health outcomes to be considered safe and sustainable agriculture (Clarke et al., 2015).

In gardens working towards contaminant remediation, recontamination by wind transportable particles and soil splash from heavy rain remain prevalent problems in areas with high heavy metal concentrations. Fine particles have higher concentrations of bioavailable Pb and are more transportable by wind compared to larger particle sizes (Sharp & Brabender, 2017). Thus, in order to mitigate recontamination risks, gardeners must reapply compost to raised beds and plots on an annual basis. Fitzstevens et al. (2017) found that municipally or other sourced compost can cap urbanized Pb contaminated soils to successfully limit contaminant exposure while positively contributing to urban agriculture. Their proposal works to reduce human lead exposure while enhancing food security in low-income neighborhoods where populations of color live with disparate environmental pollution. It proves that there are accessible methods in addressing challenges urban gardeners face concerning the consequences of using lead-contaminated urban soils as a growing medium.

Science outreach and communication

There are poor scientific translations and dissemination of research findings to stakeholders that are closely involved with the issue in question, specifically concerning the safety of working directly with heavy metal contaminants while promoting the highest crop yield, fruit set, and quality. In neighborhoods affected by food deserts and the lack of fresh foods, individuals may rely on the health, social, environmental, and economic benefits associated with supporting and participating in urban green spaces (Kim et al., 2014). Urban gardens beautify abandoned spaces, decrease the amount of time and gas to purchase fresh foods outside of the neighborhoods, and provide green education opportunities (Kaiser et al., 2015b). Yet, when encouraging humans to work with these potentially contaminated soils to supposedly better their health, health-focused protocols must be met to ensure the safety of the individual. Modern education and outreach methods fail to properly educate citizens of these lower income neighborhoods in terms of heavy metal exposure in the soil and subsequent health risks (Kaiser et al., 2015; Kim et al., 2014). As Kaiser et al. (2015) found, gardeners within the Cleveland area desire to have more information regarding site history of urban gardens, yet common gardeners may lack the expertise necessary to conduct an in-depth site history.

Participatory action research in this context is centered on the notion that the researcher of agricultural sciences will recognize and participate within the urban agriculture landscape, placing the hard-working individuals with that of the stakeholders. Many food system scholars and others seek out a common way to collaborate with researchers, practitioners, community members, and social movements in promoting food justice and safe agricultural practices (Campbell, 2004). However, Neef & Neubert (2011) found that some agricultural researchees believe that they are already employing these important participatory methods through surveys with local farmers and traders. While the connection between available research and land owners seems to be blatantly lacking, there are still controversies in the debate on the usefulness and significance of implementing participatory approach in agricultural sciences (Neef & Neubert, 2011).

Community impacts of soil contamination

Within the last two decades in the United States, deindustrialization of urban areas has resulted in increased vacant lands in cities. Abandoned manufacturing industries are typically found within neighborhoods of vacant or low income housing (Kaiser et al., 2015). Cleveland, Ohio is a large, industrial metropolitan city holding over 3,000 acres (1,214 ha) of vacant lands. In many lower-income communities, access to fresh and healthy foods is not always a given, food deserts surround neighborhoods where healthy and fresh produce is limited in place of cheap fast food options, making it difficult for populations to maintain good health. The USDA defines low-access communities to fresh foods if at least 500 individuals or at least 33% of the population reside more than a mile from a supermarket or large grocery store (American Nutrition Association, 2010).

Regarding the growers themselves, increased exposure to heavy metals can cause deleterious effects in human health (Hough Rupert L et al., 2004). Contaminants may enter the body through the inhalation of dust, direct ingestion of soil, and consumption of foods grown in contaminated soils (Kaiser et al., 2015b). Due to the health effects on both producer and consumer levels, it is increasingly important to determine the levels of contamination within the soils before the transformation into productive agricultural spaces. 17.5% of children in Cleveland have been reported to have excessive blood lead levels (>5pg/dl) by the Cuyahoga County Board of Health (Kaiser et al., 2015b). Sarwar et al. (2017) additionally noted that when lead toxicity inflicts children, symptoms may include renal failure, cardiovascular disease, reduce intelligence, short term memory loss, lack of coordination, and decreased learning abilities.

Additionally, a variety of barriers may be causing urban gardeners and farmers to deter from testing their soils for contaminants. While testing for basic heavy metals is typically inexpensive, if site history data suggests testing for additional contaminants (such as asbestos), the tests can become more costly. Kim et al. (2014) found that urban gardener informants thought the process of testing soils may be too complicated and suggests accessible or government-testing available. Another major barrier may be the fear of discovering high contamination levels after investing in the land. Kim et al. (2014) also noted that some gardeners may mix up tests of soil fertility with soil contamination levels, causing a non-regulated interpretation of results. Urban gardeners must have proper information regarding contamination concerns and how to combat potential exposure. For example, Kim et al. (2014) surveyed gardeners in Baltimore and found that informants were more concerned with chemicals being added to the garden environment over what contaminants were already present in the soil. Additionally, survey results pointed that soil contamination is often a lesser concern for gardeners and volunteers at urban farms as there is a sense of trust that the appropriate steps had already been taken to ensure soil safety. Increasing education is especially important in post-industrial cities to determine the detriment of potential contaminants may be. Increased accessibility, such as a central repository, to pertinent information regarding land use history, soil remediation, and soil testing is required to ensure heightened safety to urban gardeners, farmers, and children.

Purpose of study

The main objective of this study is to determine the effects of heavy metal contaminated soils on plant and insect performance. Additionally, we hope to find a significant correlation between fertilizer types that can potentially mitigate the harmful stress heavy metals have on plants in agricultural settings. When faced with high levels of lead in the soil, *S. exigua* will become more productive as an herbivorous insect due to abiotic stress inducing cross talk between JA and SA-induced defensive pathways, minimizing the defense mechanisms JA can perform targeted at *S. exigua*. In comparing fertilizer types, there will be less BAW survivors under organic fertilization rather than synthetic. Utilizing the findings of this study, we hope to develop a greater understanding of science communication and work to generate a lay public accessible bulletin for the urban gardener concerned with soil contamination.

The purpose of this study is to gain a greater understanding of the effects of soil heavy metal contamination and remediation on crop plants and herbivores. Additionally, this study seeks to shed light on strategies for improving communication of scientific information on soil remediation to urban gardeners and the general public. The overarching objectives of this study are to evaluate the effects of Pb-contaminated soils on tomato plant defenses and Beet Armyworm (*Spodoptera exigua*) growth and development and to create an information bulletin on soil remediation that presents applicable scientific information on heavy metal remediation strategies to the public in an accessible manner.

The soils utilized for this study were taken from two low income neighborhoods within Cleveland, Glenville and Fairfax, both of which have limited access to affordable, fresh, and healthy foods. Moneymaker tomatoes (*Solanum lycoperscium*) were planted in different metal contamination levels. *S. lycopersicum* is an indeterminate heirloom tomato variety. Beet Armyworm (BAW) has an environmentally taxing role as a polyphagous pest, meaning that the accessibility of numerous diverse host plants plays an important role in creating a population outbreak. Although outbreaks are not regular, they can easily develop due to older larval instars, becoming more resistant to common synthetic insecticides (Mardanin-Talaei 2012). Infesting over 170 plant species worldwide, *S. exigua* is an important pest to manage and can also act as a useful model of a polyphagous insect. *S. exigua* larvae have biting-chewing mouthparts—mechanisms that may play into the effects on defensive pathways within the tomato plants. To achieve maximum rates of growth and survival, Beet Armyworm larvae typically require a dietary P:C ratio of at least 28%: 14% (Lemoine & Shantz, 2016).

The next chapter will focus on looking at how lead levels in soils is remediated by OM the experiment itself by revolving around the central ecological question, it will contain a smaller introduction to the study, materials & methods, results, and discussion sections. The third chapter deals with how scientific data is presented to the public—while the introduction consider literature an evidence of how citizens are able to access pertinent scientific research, the majority of this chapter will be a written bulletin detailing this study and how it may pertain to public interest. Lastly, the fourth chapter of this paper will summarize and bring together the pieces of information throughout the IS conclude the information and data obtained throughout the previous chapters.

CHAPTER 2: EFFECTS OF HEAVY METAL CONTAMINATED SOIL ON PLANT AND INSECT GROWTH AND DEVELOPMENT

Introduction

Urban agriculture

Urbanization heavily alters soil functioning, hydrological systems, and ecosystem services. As defined by Egerer et al. (2018), soil functioning regards the ability of soils to promote ecological and hydrological systems such as decomposition and water and nutrient cycling. Juxtaposed with traditional agricultural or undisturbed natural soils, urban soils often exhibit lower organic matter contents, increased compaction, and the presence of physical and chemical contaminants (Egerer et al., 2018). As cities' populations continue to expand, urban areas are developing agricultural systems ranging from community gardens to aquaponic farms to increase food access across the city.

Urban agriculture (UA), as defined by Nogeire-McRae et al. (2018), includes the production of vegetables, fruits, and livestock (namely chickens) and consists of home, community, and market gardens located within urban environments. Consumer interests are currently on agricultural practices that provide food with fewer environmental impacts, causing an increase in UA development (Nogeire-McRae et al., 2018). Globally, urban agriculture accounts for 5 to 10 percent of legumes, tubers, and vegetable production (O'Sullivan et al., 2019). However, despite the rapid expansion of city grown food, the costs and benefits of UA to society remain poorly understood (Nogeire-McRae et al., 2018). Since these farms and gardens are small scale and spatially disbursed throughout a city, they create opportunities to redirect excess resources such as nutrients, water, and energy; although there is still a need for innovations to use waste resources economically and safely (O'Sullivan et al., 2019).

If further researched, UA could play an important role in mitigating climate change effects, carbon and water footprints, and improving soil functioning and ecosystem services within urban ecosystems. From a management perspective, there is a growing need to further understand ecosystem services of urban soils for food production and resource conservation. Examples of management decisions include remediating soil degradation or contaminants, increasing soil fertility, and increasing water holding capacity (Egerer et al., 2018). Dependent on location and methods of production, UA may increase habitat value for pollinators and other beneficial wildlife and lessen carbon and water footprints by recycling gray water, organic household waste and utilizing excess energy from the city (Nogeire-McRae et al., 2018). Lastly, growing produce in home or community gardens offsets consumer greenhouse gas emission from produce through conventional agribusiness systems. While urban agriculture has been largely ignored by conservationists, it may provide immense services in mitigating urban ecosystem services and reducing footprints.

Soil contamination & land management

Cities often possess histories of many diverse industrial practices, which over time contaminated urban soils with heavy metals and other pollutants. Other common sources of urban soil contamination includes busy roadways (roadside pollution infiltrates soil over time) and lead paint in residential areas (Clarke et al., 2015). While some metals present in soils result from natural processes, inherited from bedrock from which they originated, the majority of metal contamination is anthropogenic—due to legacies of air and soil pollution (Clarke et al., 2015; Sarwar et al., 2017). In order to develop healthy food systems in urban environments, land managers must first implement strategies to mitigate contamination as heavy metals do not biodegrade and are continuously accumulating in the environment without intentional remediation (Sarwar et al., 2017).

When contaminated with heavy metals, soils can naturally reduce mobility and bioavailability, or the portion available for plant uptake, of the pollutants through sorption (absorption of contaminant into soil), precipitation (contaminant within soil and water transforms into solid) and complexation reactions (transport and transform contaminants) (Farrell & Jones, 2010). This natural remediation process can be accelerated by adding organic amendments to the soil. Historically, heavy metal removal was generally executed by disposing of the contaminated soil and importing clean soils from another location. This method results in high economic costs, limiting its use on larger contaminated areas, and significantly affects soil structure (Farrell & Jones, 2010). Liu et al. (2020) found that organic soil amendment beneficially altered mobility and bioavailability of heavy metals in soil, overall decreasing concentrations in crops grown in contaminated soils treated with organic amendments. Much additions also tended to increase soil functioning by increasing water holding capacities and fertility.

Egerer et al. (2018) noted that mulching tends to be more present in urban neighborhoods with higher education, better access to transportation, and increased housing opportunities. The relationship between socio-demographic characteristics of gardeners and their neighborhoods and access to organic amendments (financial or transportation barriers), may heavily influence the ability to manage these soil-based ecosystems (Egerer et al., 2018). To mitigate these effects across socio-economic backgrounds, other management practices including composting, cover cropping, and using diverse source of organic matter (green waste, manure, food waste) may be equally effective than mulching in improving water conservation and fertility (Egerer et al., 2018). Increased effective communication strategies may aid in relaying these remediation methods in an accessible manner to urban gardeners.

The ability of crop plants to resist or tolerate insect pests and diseases is directly tied to soil functioning, specifically optimal levels of physical, chemical, and biological properties (Altieri & Nicholls, 2003). Organic soil amendments have been researched as cost-effective methods to remediate heavy metals in soils by lessening mobility and bioavailability (Altieri & Nicholls, 2003; Liu et al., 2020). Through similar studies comparing fertilizer usage on soils and pest resistance by the crops, there appears to be a correlation worth studying between organic fertilization of soils and increased pest defense by the plants through induced phytohormones, or plant hormones (Chen et al., 2008; Lange et al., 2019; Rowen et al., 2019). Additionally, Rowen et al. (2019) found significance between using animal manure as an organic fertilizer and pest suppression by the alterations of the macro- and micronutrient concentrations in the plant, increasing the plant's production of defensive chemicals, and altering herbivore-induced plant defense mechanisms.

Study introduction

While the practices of vacant lot agriculture and community gardens continue to rise in popularity around the globe, there is still a large research gap on urban soils and proper remediation tactics for common contaminants. My study worked to further understand the effects of soil amendments on lead contaminated soils and the effects of lead and soil remediation via organic matter on Beet Armyworm (*Spodoptera exigua*), an insect pest of tomatoes, and plant development. Findings from this study aid in proposing more efficient methods for soil remediation in urban agricultural systems. My experiment utilizes Moneymaker tomato (*Solanum lycoperscium*) plants grown in different lead contamination levels with either organic or synthetic amendments added. *Spodoptera exigua* larvae growth and development on each treatment will determine the effects of plant defense hormones. I expect to find statistically greater levels of *S. exigua* survivorship and weight in the high Pb treatment and synthetic soil amendments. With organic soil amendments, I expect for Pb bioavailability and mobility within the soil to decrease, causing increased plant defenses against *S. exigua*, resulting in lower survivorship and growth.

Methods

Study system

Beet armyworm (*Spodoptera* exigua) is a common worldwide pest originating from southern Asia with introductions to other regions spanning from the 19th century (Mehrkhou 2015). Often infesting greenhouses, beet armyworm are economically important pests of tomato, sweet pepper, cucumber, melon, and watermelon (Aguirre 2013). Of field crops, beet armyworm causes significant economic damage in the Brassicaceae, Solanaceae, and Fabaceae families. Young larvae tend to skeletonize host foliage, leaving main veins larger intact. As they grow, they disperse as larva and create irregular holes among the foliage or burrow into the crowns of lettuce (Mardanin-Talaei 2012). A complete generation of *S. exigua* is completed within 21 to 35 days, with often 5 or more generations annually. Early instar larvae hatch within 2 to 5 days, feeding in groups. Development rates are determined by temperature (Meister Publishing 1997).

Moneymaker variety tomato seeds (*Solanum lycoperscium*) were purchased from Urban Farmer LLC in Westfield, Indiana. Moneymaker is an indeterminate, midseason heirloom tomato variety originating from England. *S. lycopersicum* grows best in hot humid climates and in greenhouses. Germination typically occurs between five to ten days with 77 days to reach maturity. Vines can grow up to six feet with a typically high crop yield (*Moneymaker, Tomato Seeds—Urban Farmer Seeds*, n.d.).

Soils were collected from vacant lots within the city of Cleveland, Ohio in the Fairfax and Glenville neighborhoods (Figure 1). The closest points within each of the neighborhoods are less than a mile in distance (Figure 1A). Fairfax neighborhood (Figure 1B) has historically housed numerous industries since it was annexed to the city of Cleveland in 1872, including Ohio Foundry Co. (1893), National Malleable & Steel Castings Co. (1891), and Peerless Motor Car Corp. factory (1889) (Roy, n.d.-a). Since the first great migration in 1930, Fairfax has been a predominately African American community, with 97% individuals in 2010. The majority of the population makes less than $10k per household annually (*Fairfax SPA*, n.d.). Glenville neighborhood (Figure 2B) was incorporated as a village in 1870 and formally annexed to the city of Cleveland in 1905, with New England farmers being the first to settle in the community. In 1870, the Glenville racetrack opened, becoming a major horseracing center while also hosting auto, bicycle, and foot races. In the 1890's, the lakeshore destination was popular and common for upscale summer residences. By the 1960's, the neighborhood becomes, and continues to be, predominately African American (Roy, n.d.-b).

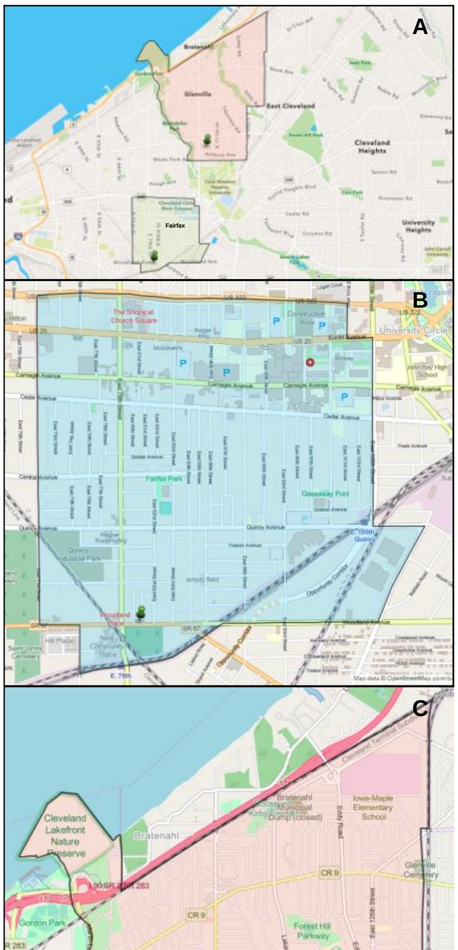

Figure 1. Map of Glenville and Fairfax neighborhoods in Cleveland (A). Current industrial landscape of Fairfax (B) and Glenville (C). Pins represent vacant lots.

Two locations were allocated per site and three soil samples were collected from the top 15 cm at each site and all six samples were composited per vacant lot. Soils were sieved to 2mm and organic debris was removed prior to analysis. Particle analysis was conducted to find percentages of sand, silt, and gravel (Figure 2). Heavy metal analyses were conducted and resulted in comparatively low levels of lead within urban soil, considering EPA regulations (Table 1). Lead represents an average of 444.4 parts per million (ppm) in the tested soils. Regulations within the United States limit the presence of lead in soil to 400 ppm in play areas and 1200 ppm in non-play areas (ATSDR, 2017).

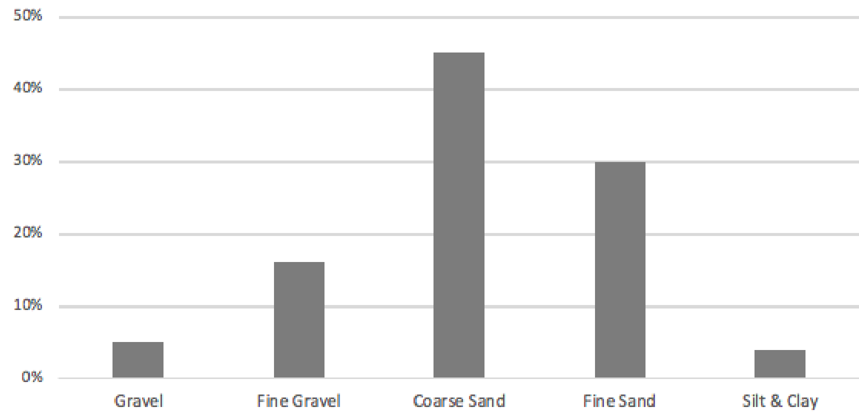

Figure 2. Percentage of particle size by weight. Particle size organized from largest to smallest, from left to right.

Soil contamination procedure

Table 1. Average of elements (ug/g of soil) between soils of each

Element	ug/g
As	13.532
Cd	5.746
Cr	23.455
Cu	14990
Fe	3041.5
Li	3658
Ni	456.95
Pb	**444.35**

Soils were spiked with lead to form three groups: control (0 ppm), medium contamination (550 ppm; slightly above the EPA limit), and heavy contamination (2000 ppm, very high levels of Pb but not extreme for urban soils). A stock solution of Lead (II) Acetate trihydrate was made with Pb levels at 207,200 ppm. The solution was diluted per treatment to equal the appropriate level of ppm to enter the soil. Diluted solutions were slowly mixed into the soil and placed in the greenhouse to dry out for accurate weighing.

After separating the soils by Pb contamination rates, each individual soil type group was halved and either mixed with organic compost (Sweet Peet from Urban Organics; New Brunswick, Ohio and Bloodmeal from Jobe's Organics; Waco, Texas) or synthetic fertilizer (Scotts Miracle Grow Company; Marysville, Ohio). Synthetic fertilized pots contained 400g of soil and 0.8g of Miracle Gro (1.8% N) and pots with organic fertilizer contained 360g of soil, 40g of Sweet Peet (1.46% N) and 5.5g of bloodmeal (12.0% N). Soils were mixed with each fertilizer in a separate container before being placed within the pot.

Seven tomato seeds were planted in each 3-inch diameter cone pots, with each experimental replicate including 6 pots, one pot representing each treatment (Figure 3). A randomized complete block design was configured with 6 pots per experimental block, with two blocks held in each holding rack.

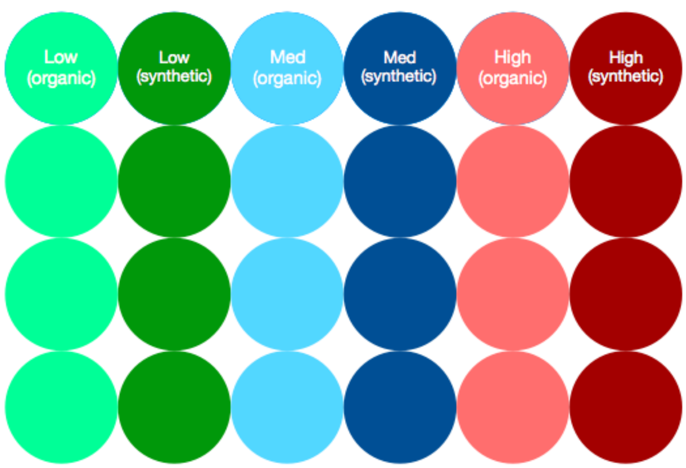

Figure 3. Pre-randomized layout of experimental blocks regarding low, medium, and high lead levels with each amendment type represented per group.

Two racks were placed in the growth chamber under 14 h of light cycle at 25°C and 10 h of darkness at 22°C. Each pot received approximately 100 ml of water every other day.

Beet Armyworm bioassay

When the tomato plants reached the 4th true leaf stage (about 3 weeks post-germination), two opposite leaflets were removed from the youngest fully expanded leaf using sanitized scissors. Leaflets were harvested closest to the petiole. Leaflets were placed inside a labeled plastic bag per plant and kept in a container filled with ice for transfer from the greenhouse to the lab. Surface area of each leaflet was calculated using ImageJ (Version 1.52q; Rasband, 2015).

The two leaflets of the same plant were placed in separate petri dishes with moist filter paper, a drop of deionized water was added between the filter paper and the petiole. Using a fine paint brush, 5 larvae were placed on each leaflet and the petri dish was sealed with 2 rubber bands. Petri dishes were placed inside the growth chamber at 25°C with a 14:10 h light to dark period. After three days, surviving larvae were transferred to a weighing dish and counted and weighed using a scale with sensitivity <0.001g. Day 3 weights were calculated by dividing weight by the surface area of the initial leaflet. Survivorship for day 3 was calculated by measuring the percentage of surviving larvae and dividing it by leaf surface area.

New leaves were harvested from the initial plant. The first leaflet was discarded and replaced with the fresh sample and surviving larvae were transferred. At day 6, surviving larvae were counted and weighed. End weights were measured by dividing day 6 weights by leaflet surface area. Final survivorship was measured with the percentage of surviving larvae per dish divided by leaf surface area. Surviving larvae were frozen for one day and then discarded, as required by USDA permit.

Tomato metabolomics

GC/MS analysis of metabolomics was conducted with EZ:Faast family of amino acid analysis kits; methods outlined by Badawy (2012). Each sample was run twice: as a splitless injection and a split injection. The splitless method detects small amounts of compounds while the split works to better quantify large peaks of a compound.

Timeline of experiment

From January to February 2020, 8 experimental replicates were completed. Plantings occurred during early January 2020. Of the 8 blocks, 4 blocks were transferred into the greenhouse post-germination due to spatial constraints.

Statistical analysis

Interactions and main effects of two independent variables (Pb levels x soil amendment) on the dependent variables (larval survivorship by leaf area and larval final weight by leaf area) were tested using a multivariate analysis of variance (MANOVA). All data was analyzed using SPSS software (Version 25.0; IBM Corp., 2017). A multivariate analysis of variance worked to determine the association of Pb contamination and soil amendments (factors) on survivorship and final weight (dependent variables). To ensure that the assumptions of MANOVA were met, homogeneity and normality of error variances were tested by the visual assessment of residual plots and the Shapiro-Wilk Test. Data was log transformed to meet these assumptions.

Results

Generally, larval final weight per unit leaf area appeared to be lower in treatments with lower Pb contamination levels relative to higher Pb levels (figure 4, F value: 2.677, P value: 0.84). Low Pb contamination groups had final weight means of 0.154 and 0.168 for organic and synthetic soil amendments respectively (SD for organic treatment: 0.167; SD for synthetic treatment: 0.118). Medium Pb contamination groups had final weight means of 0.210 and 0.343 for organic and synthetic groups (SD for organic treatment: 0.159; SD for synthetic treatment: 0.216). Lastly, high Pb contamination had final weight means of 0.346 and 0.515 for organic and synthetic amendments (SD for organic treatment: 0.300; SD for synthetic treatment: 0.556).

The results of the MANOVA indicate that larval survivorship of *S. exigua*, or the percentage of surviving larvae on day 6 divided by leaf surface area, was not statistically significant across Pb contamination and soil amendment main effects (figure 5, Pb treatment: F value:1.422, p value:.256; soil amendment: F value:.814, p value:.374). Similarly, MANOVA results expressed that larval final weight, or day 6 weights divided by leaf surface area, was not statistically significant across Pb contamination and soil amendments treatments levels (figure 4, Pb treatment: F value: 2.677, P value: 0.84; soil treatment: F value: 1.219, p value: .277). The GC/MS analysis found inconclusive results on JA/SA profiles in the plants, likely due to difficulty identifying phytohormones within the dataset.

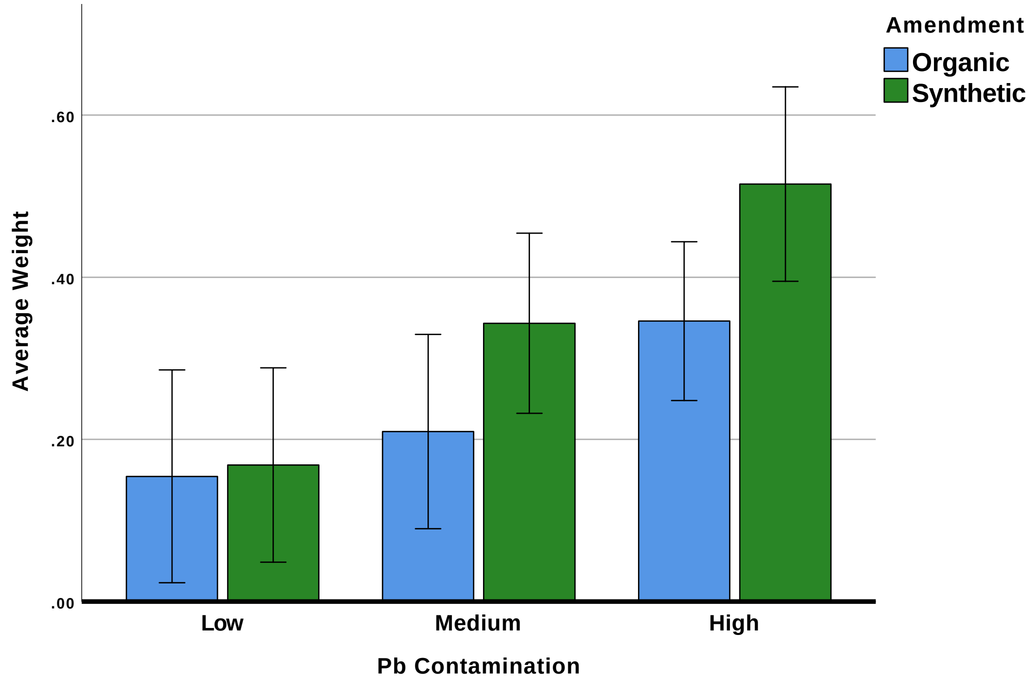

Figure 4. Average *Spodoptera exigua* final weight (day 6) across treatments (8 replicates; low: N=11, medium: N=13, high: N=15). Each bar represents either organic (blue) or synthetic (green) soil amendments. There was no significant difference found across contamination levels (p:.084, F:2.677, df:2) or across soil amendments (p:.277, F:1.219, df:1). Error bars represent +/- 1 standard errors.

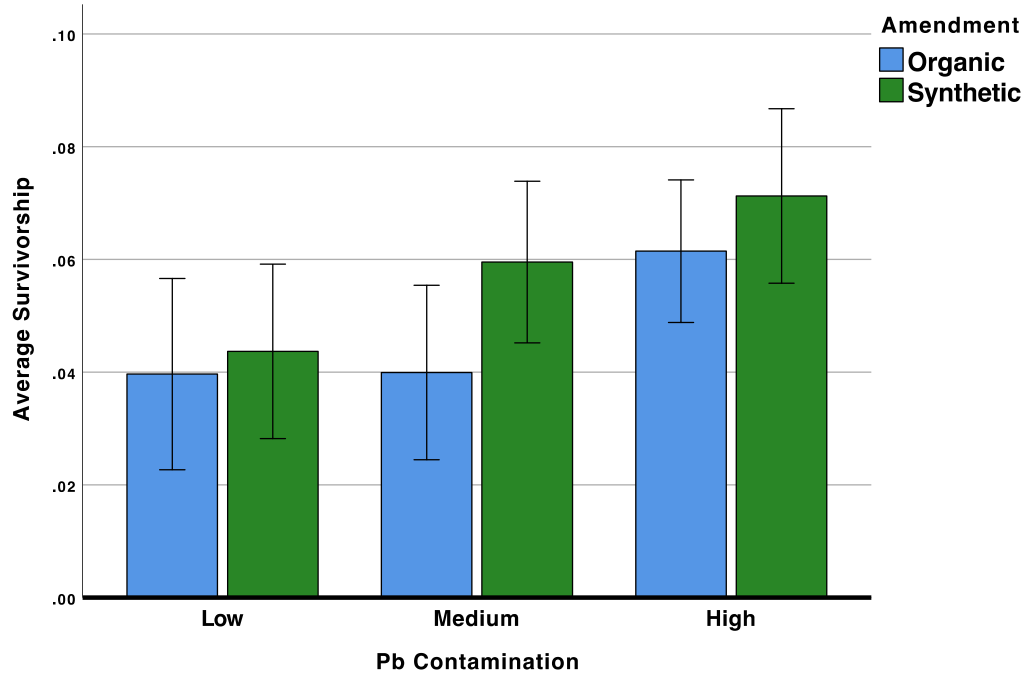

Figure 5. Average survivorship of *Spodoptera exigua* observed in each treatment (8 replicates; low: N=11, medium: N=13, high: N=15). Each bar represents either organic (blue) or synthetic (green) soil amendments. There was no significant difference found across contamination levels (p:.256, F:1.422, df:2) or across soil amendments (p:.374, F:.814, df:1). Error bars represent +/- 1 standard errors.

Discussion

Prior to beginning the experiment and conducting statistical analysis, it was hypothesized that *S. exigua* larvae would exhibit higher rates of survivorship and growth in higher levels of Pb contamination with synthetic soil amendments. The results of the MANOVA do not support my hypothesis, as there was no significance of *S. exigua* surviroship or growth (final weight) across either treatment (Pb contamination or soil amendment). However, the data exhibits an emerging yet statistically insignificant trend that larval growth was higher in medium and high Pb contamination treatments with synthetic soil amendments added compared to low Pb contamination or organic amendments. The lack of significance may be partly due to experimental error, as the growth chambers utilized did not have mechanisms to hold constant humidity and *S. exigua* appeared to exhibit potential decreased survivorship because of it.

Altieri & Nicholls (2003) noted that crop resistance against pests and diseases was directly correlated with soil health, finding that plant defense mechanisms against external stressors were most effective when soils had higher organic contents. This study did not produce similar results concerning soils without contamination, as the low Pb treatment exhibited similar results across each analysis despite the type of soil amendment. However, these results may have been affected by too small of a sample size—especially in low Pb contamination treatments (Low: N = 11; Medium: N = 13; High: N = 15). Other studies have similarly found that organic compost and fertilizer added into soils have significantly increased pest suppression through induced phytohormones from the affected crop (Lange et al., 2019; Rowen et al., 2019).

Assuming that these studies are accurate in the assumption of organic amendments increasing pest suppression, while not statistically significant (p-value > 0.05) my study yields similar results when concerning heavy metal contaminated soils. This follows the literature in that organic soil amendments aid in the remediation of contaminated soils by altering the mobility and bioavailability of present heavy metals (Farrell & Jones, 2010; Liu et al., 2020). If organic amendments are able to aid in the natural remediation processes of natural soils, it makes sense that a biological relevant trend of increased growth of *S. exigua* larvae was found in synthetic treatments compared to organic in both medium and high Pb contamination treatments. My data is able to further demonstrate organic soil amendments are increasingly important in urban contaminated soils in terms of plant defense phytohormones and subsequent pest suppression. This study requires increased replication and fluid methods to statistically demonstrate this notion, but my results are able to further the discussion on remediation methods and the importance of soil amendment choice.

Heavy metals are unique contaminants because they do not naturally degrade and thus continue to accumulate in the environment (Sarwar et al., 2017). Therefore, in encouraging further expansion of urban agriculture and community gardens, it is necessary to have a thorough remediation plan to target heavy metal soil contamination. Not only does this contamination affect crops and the ability to fight pests and disease, but it can negatively affect human health by direct contact with soil or the consumption of contaminated produce.

Yet, the popularity of vacant lot agriculture and the overall growth of urban agricultural systems provide many personal and ecosystem services. By further understanding soil health and proper remediation methods to maintain healthy gardening, urban agriculture may benefit the city by utilizing otherwise wasted energy, water, and organic waste (Nogeire-McRae et al., 2018). This study, along with others, promotes intentional expansion of urban agriculture; highlighting the importance of understanding the soil in maintain a healthy agricultural system in a city.

If conducting a similar study, increasing the sample size may aid in concluding significant results. Additionally, it would be beneficial to recreate this study through the lens of plant defense mechanisms and phytohormones and analyze the concentrations of jasmonic and salicylic acid. The study may further benefit by placing the larvae on the plants themselves rather than a leaf at time, as it may trigger further defense mechanisms. My experiment along with future, similar studies will prove beneficial as the field of urban agriculture continues to grow and develop healthy methods for development.

CHAPTER 3: EFFECTIVE SCIENCE COMMUNICATION OF URBAN SOIL REMEDIATION

While food safety and security remain major challenges in large cities, there is a growing interest in urban agriculture and gardening in deindustrializing cities. Positive benefits of community agricultural systems are centered around health—increasing access to fresh foods and promoting regular exercise. However, agricultural systems set in sites of historic industrial practices may undermine the positive benefits due to legacy heavy metals and other pollutants contaminating the soils (Wong et al., 2018).

The development of urban agricultural systems is vital when concerning food justice; increased agricultural development has been most prevalent in low-income urban communities of color. These communities more often contain heightened lead and heavy metal contamination and less communication revolves around soil testing and healthy remediation practices (Henry et al., 2015; Sharp & Brabander, 2017). This study works to identify applicable communication styles that will help enhance the flow of knowledge and information between scientific research and the lay public. The best communication strategies will be determined, culminating in a bulletin written to the public regarding the risks and remediation strategies of contaminated soils in urban gardens.

As urban gardens continue to rise in popularity and prevalence, the integration of research findings and evidence into policy and practice is important to mitigate negative environmental and health effects. For example, Johnson et al. (2016) noted that standard lead exposure prevention education materials highlight that individuals can reduce lead absorption in their homegrown vegetables if they increase planting and consumption of green leafy vegetables in their gardens. Yet, no matter the type of vegetable grown, contaminated dust may remain on the food. Statements such as these simplify the drastic nature of the issue, by encouraging individuals to focus on what to plant rather than remediation strategies implemented prior to lead exposure.

Management of agricultural and gardening practices have historically faced difficulties in decision-making due to the failure of varying scientific fields collaborating to provide clear and concise information (Augustsson et al., 2018; Barbercheck et al., 2012). This increases the disconnect between scientific knowledge with the application decisions made by land managers. When encouraging backyard and community gardening, the consequences of heavy metal exposure risk from soil must be detailed to ensure there are no unintended health consequences (Johnson et al., 2016). When promoting knowledge to land managers, all pertinent information must be clear and present to ensure beneficial results.

Research on effective knowledge sharing works to identify the pathways where research and information flows from a specific set of people (i.e. scientists) to a specific set of consumers (i.e urban farmers). The pathway typically moves from researchers to governmental agencies, from agencies to practitioners, and lastly to policymakers (Gano et al., 2006). For example, as scientists recorded increasing data regarding negative soil contamination effects, the Center for Disease Control and Prevention used the collected data and knowledge to promote primary prevention remediation methods to the public, with a focus on eliminating contamination prior to exposure (Johnson et al., 2016). In studying the patterns of knowledge flow—or how knowledge moves through individuals—strategies are utilized to lessen the knowledge disconnect between research, policy, and natural resource management (Roux et al., 2006).

Concerning urban agriculture specifically, there are substantial gaps in communal knowledge regarding the risks of soil contamination and exposure pathways to the individual (Augustsson et al., 2018).With high amounts of research going into urban agricultural systems, an enhanced knowledge sharing system is required to ensure effective understanding and utilization of knowledge. When transferring knowledge on urban agricultural and soil remediation practices from an expert to the commonplace individual, there may be discrepancies between sharing knowledge without the guarantee of the receiver understanding (Roux et al., 2006). This is important to note as information is disseminated to urban gardeners with varying education demographics.

From a written context, science communication provides accessible scientific information in context across disciplines and prevalence within other communities (Szymanski, 2016). However, there are drastic differences of writing styles between peer-reviewed papers written for other scientists and written bulletins to present scientific research to the lay public. Few studies focus on key strategies for scientists on communication with media and the public, and public communication is often left out of academia for students in STEM fields (Baram-Tsabari & Lewenstein, 2013).

In encouraging scientists to present their research in accessible manners, education systems have to work in teaching communication strategies across audience types. The use of scientific jargon, for instance, has the effect of making individuals of different communities feel alienated or excluded from the information (Baram-Tsabari & Lewenstein, 2013). When presenting information, it's important to recognize the intended audience; Burke et al. (2016) note the three key aspects of audiences that measure the effectiveness of science communication: prior knowledge, the ability to understand the information, and knowledge of interpreting new information in the proper context. In order to reach the desired audience, communication must be framed in the proper context to ensure the public's understanding.

The effective conversion of science writing heavily relies on the use of nontechnical language that individuals can follow outside of scientific communities. Baram-Tsabari & Lewenstein (2013) created detailed suggestions, summarizing themes of practical science community advice literature. Firstly, the content of the written piece must have clear and concise themes—the purpose of the writing is obvious to the reader. When converting scientific information into a readable article or bulletin, abundant information is to be avoided and rather a clear focus repeating the main points of the paper through different examples. Language should be kept simple, avoiding jargon, abbreviations, and acronyms. While generating a readable and easy to understand piece is the end goal, it is just as important to ensure the engagement of the reader—this is often done through picture, graphics, and enthusiasm about the topic. In developing a written bulletin targeting the health effects of urban agriculture and how to remediate soils, the author needs to prove themselves as worthy on the topic through personal stories or anecdotes prior to explaining suggested remediation methods.

Need for enhanced communication

Due to the numerous and untraceable sources of heavy metal contaminants within urban soils, primary prevention techniques focusing on periods prior agricultural development will the most important in lessening health effects through exposure. Ultimately, all levels of exposure to lead are unsafe; lead exposure is often an environmental justice issue that has and continually contributes to racial inequalities, especially in urban environments (Fitzstevens et al., 2017). Fitzstevens et al. (2017) notes that lead exposure prevention programs must prioritize identifying historical heavy metal sources in soils rather than that of the surrounding environment, leaded paint, etc. With primary prevention at the forefront of remediation, dissemination of information must be readily available prior to the start-up of an urban farm or garden. Developing a readable and detailed bulletin on remediation methods and the health consequences of contamination will provide urban gardeners with the tools necessary to perform soil contamination tests and work with the soil prior to growing food.

Encouraging urban growers to utilize organic compost amendments to lessen contamination effects will also promote the use of organic matters rather than building a continual reliance on chemical fertilizers and pesticides. Promoting the utilization of organic compost will consequently nourish the soil and lessen the bioavailability of Pb and other heavy metal contaminants within urban soils. The bulletin may detail affordable methods of acquiring organic compost within the region. As research expands, the information catered to the public should encompass increased and updated material.

With increasing popularity of urbanized agriculture, there is beginning to be a surplus of scientific literature studying the system. Yet, there still remains a disconnect between that of researchers and the individuals directly involved with the benefits and negatives of urban farming. In order to ensure safe and cost-efficient practices, more disciplines need to use their energy in studying different aspects of urban gardening and how to promote found knowledge to the public. Knowledge sharing is a complex and difficult action to complete accurately, the transformation of base information from research into individual knowledge of society will influence the spread of knowledge regarding safe and practical urban farming and gardening.

Case studies

Surveys of community gardens in St. Louis, Missouri discovered that the majority of surveyed gardeners were not concerned about the potential contamination of urban soil. The benefits of community gardens were viewed as greater than concerns about soil contamination (Wong et al., 2018). Kim et al. (2014) surveyed urban gardeners in Baltimore, Maryland and found that individuals had concerns regarding soil contamination but had trust in urban farms already in place that the appropriate steps had been taken. The average response from Baltimore individuals when measuring the overall levels of concern about contaminants in urban gardens was 2.3/5 on a numerical survey. Many informants cited that building raised beds that contain clean and imported soil as the safest and most cost-efficient method of managing contaminants. However, there is potential for the imported soil to be contaminated (if not tested prior to use) and that the plant roots may extend below the raise beds, allowing bioavailable contaminants to enter plant tissues (Kim et al., 2014).

Informants from numerous surveys regarding urban gardens and farms request the need for a form of government regulated repository with accessible information regarding soil contamination (Kaiser et al., 2015a; Kim et al., 2014; Wong et al., 2018). The data suggests that urban gardeners are not properly informed regarding the risks of heavy metals present in urban soils. Due to this, community members may be less knowledgeable about the potential health risks of consuming contaminated produce grown in untested soils.

With differing information available about the best and most cost-efficient methods of remediation, urban gardeners without great levels of multidisciplinary support systems are left behind from novel and effective methods. Survey participants from Cleveland, Ohio stated that while they had some desire to test their soil, there was a lack of understanding on what procedures are required for proper testing in addition to what methods were required once the results were available (Kaiser et al., 2015a). The muddled information available limits lower-income growers to access soil safety precautions at their residences and community garden. Thus, with access to clear information regarding how to properly test soils for contamination and how to analyze the results, urban gardeners are more likely to procure a soil test and learn how to remediate the soils prior to growing food.

Located in the appendix, this bulletin works to promote the knowledge about soil contamination and what urban gardeners can do to ensure they are practicing safely. Using strategies highlighted, this written bulletin will be engaging to the reader through personal reflection and images and accessible by limiting the use of jargon and abbreviations.

While many of the documents available to the public detail the appropriate methods for remediation soils, few do so in a manner focused on the lay public. In providing this pertinent information in such a dense format, it provides urban garden individuals a disservice as they may lack the skills to understand the jargon-rich document. This bulletin works to sum up the dense information in an easy to read format while educating the public on government and public resources that detail healthy garden practices.

CHAPTER 4: SYNTHESIS

The primary goal of this project is to improve understanding of the effects of heavy metal soil remediation on ecosystem dynamic and public education strategies. Due to the expansive industrial network historically present in cities, most urban soils harbor an array of contaminants stemming from industrial pollution, lead paint from homes established before the late 1970s, and other anthropogenic practices (McClintock, 2012). Without accurate information regarding how to evaluate and remediate contaminated soils prior to agricultural development, urban growers may end up harming their health from soil exposure in addition to promoting produce containing bioavailable heavy metals and other contaminants.

The results of my research indicate that lead contamination can alter food web dynamics such as *S. exigua.* However, more tests are required to determine the effects of organic matter amendments on *S. exigua.* While not statistically significant, my data demonstrates a push for organic compost and fertilizer amendments over synthetic or chemical fertilizer, especially targeting higher concentrations of heavy metals. Scientific literature does exist on the topic, demonstrating that organic amendments additionally increase pest suppression through plant defense mechanisms while remediating the soils of heavy metal and chemical contaminants (citation). However, there is still little promotion of this research towards the public, causing an expansive disconnect between research and practice of urban soil remediation targeted towards agricultural practices.

After completing the experimental portion of this project, I developed a bulletin targeted for the lay public working in urban contaminated soils. I researched the most effective science communication strategies for developing a written tool to disseminate scientific research to the lay public. The primary goal of the bulletin is to bring together much of the research from my study along with others regarding urban agriculture and safe gardening with contaminated soils. The hope of this bulletin along with my overall study work to encourage increased research of urban soils along with enhanced communication between researchers and the public.

If replicated, this study would benefit from increasing the number of replicates, as more individuals may exhibit significant results. Recreating this experiment within a vacant lot may also exhibit pertinent data, such as comparing plant defenses in raised beds versus directly in the contaminated soils in conjunction with different soil amendments. Within organic soil amendments, there is great diversity, examining different organic fertilizers may exhibit different reactions of plant and insect responses. Overall, this study works as a steppingstone for future research that may build on my results to further examine plant-insect interactions in heavy metal contaminated soils. In post-industrialized cities, additional studies are needed to expand research on the necessary conditions for effective urban gardening.

APPENDIX

March 13, 2020

Benjamin Franklin Community Garden in Cuyahoga County

Urban Gardening

Understanding the risks of soil contamination

Introduction

In cities with limited access to fresh and affordable foods, urban community gardens aid with increasing access to fresh foods while enhancing opportunities for regular exercise, time spent outdoors, and creating stronger relationships within a neighborhood. Green spaces additionally provide educational opportunities for urban residents, where a farm or garden may be their only regular experience of nature. Urban gardens also contribute to vital ecosystem functions such as moderating temperature, forming habitats and foraging for beneficial organisms, and reducing storm water runoff. However, despite the numerous benefits of urban gardening—soil contamination is a big concern in cities that traditionally hosted a variety of industrial practices.

Urban Soils

Goals

This bulletin was developed to promote the tools for urban gardeners to mitigate contamination risks. Depending on previous uses of the land, urban soils may host contaminants such as lead

Source: BackYard Riches

and other heavy metals, petroleum products, and asbestos. The land use history of a site is a likely determinant of the potential contaminants within the soil.

Land Use	Source	Contaminants
Residential buildings, mining, landfill operations	Paint (before 1978)	Lead
Near heavily trafficked roads or highways	Busy Roadways	Lead, zinc, polycyclic aromatic hydrocarbons (PAHs)
Lumber treatment facilities	Treated lumber	Arsenic, chromium, copper
Landfills	Burning wastes	PAHs, dioxins
Copper and zinc salts added to feed	Contaminated manure	Copper, zinc
Farms, orchards, pesticide formulation	Pesticides	Lead, arsenic, mercury, chlordane and other chlorinated pesticides
Factories, industry	Industrial/ Commercial Use	PAHs, petroleum products, solvents, lead, other heavy metals (arsenic, cadmium, chromium, lead, mercury, zinc)

Source: Getty Images

Soil Contamination

Contaminants enter the soils through human activities, such as lead paint or burning coal, and through natural processes. In de-industrialized cities, soils are often closer to pollution sources—including busy roadways, waste dumps, and industrial practices—resulting in higher contamination rates in cities.

Source: Reader's Digest

The bioavailability of soil contaminants, such as lead, refers to the amount of a substance that can directly affect plants and animals (including humans) because it can be taken into their bodies. Site conditions often dictate the bioavailability of a contaminant, as it affects how the contaminant is held within the soil particles and its solubility. Greater solubility of contaminants, or the amount of contaminant that will dissolve in water in the soil, typically results in greater bioavailability in addition to greater chances of the contaminant leaching out of the soil.

It is difficult to determine the ideal methods and conditions required to mitigate contamination risks due to the high variety of exposure and risk variables. Exposure rates often correlate with the amount of time spent onsite, routes including inhalation (breathing in soil particles) direct contact (touching the soil), or ingestion (children putting hands in mouths, eating contaminated foods). In order to ensure the least exposure to negative contaminants, finding out the land use history of a garden site may identify specific environmental concerns to shape the testing and remediation processes.

Testing for Contaminants

Step One: Determine Land Use History

Researching past uses of the land prior to its development for community will help focus soil tests for the applicable contaminants.

-Internet searches: historical aerial photos, neighborhood maps

-Conducting interviews of neighbors and previous owners

-Libraries (governmental and academic)

-City archives and Courthouse records

Soil tests typically focus on the most common contamination types, so determining the land use history can aid in testing for additional contaminants. It is important to note that contamination risks may also be from nearby properties.

Step Two: Testing for Specific Contaminants

Many institutions throughout the United States offer affordable soil testing (see sources below). Typically, they send a test kit for collecting soil samples, and the landowner send in the samples for analysis. It is important to send in samples from different locations within the site. In determining land use history, soil tests can be altered to measure the applicable contaminants.

Source: The Spruce

March 13, 2020

Helpful Sources

Other information/ management practices

-University of California: Agriculture and Natural Resources

- Lead specific testing and remediation: Penn State Extension

- Broader Information on Urban Agriculture: Sustainable Economies Law Center

Cleveland Specific

-Cuyahoga Soil & Water Conservation District: Soil Maps & Testing

-OSU Extension: Agricultural and Natural Resources

Source: Washington Post

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