Evaluating Plant Uptake of Chemical Contaminants in Crops Grown Near Urban Gardening Sites for Human Health Risk Assessment

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Abstract: This document provides an assessment of the potential exposure routes, plant uptake pathways, and remediation practices of chemicals contaminants found in crops grown in urban gardening sites. This report will focus on both inorganic and organic pollutants that are considered contaminants of emerging concern (CECs) by the U.S. EPA. The presence of several trace elements and persistent organic pollutants (POPs) in urban soil media were analyzed on the state-level to quantify the potential contamination risk associated with plant uptake mechanisms by crops commonly grown throughout the various regions of the U.S. CECs exposure routes in urban agriculture (UA) scenarios and associated human health risks are assessed. This report also serves to provide potential remediation methods for polluted urban soils, with an emphasis on affordability, accessibility, and sustainability of the methods. The specific aims of this report will utilize the existing methods used to quantify the concentrations of chemical contaminants in urban soil media to identify regional trends and produce a guide of best practices for urban growers. A portion will be dedicated to outlining research gaps which require remediation to facilitate a more accurate characterization of potential exposure of CECs to ensure enough data is provided to form national screening levels.

*Keywords***:** Plant uptake; Soil contamination; Risk assessment; Urban soils; Contaminants of emerging concern (CEC); Heavy metals; Persistent organic pollutants (POPs), State models

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1. Introduction

Urban gardening has gained significant popularity in recent years, providing individuals and communities with opportunities to cultivate their own fresh produce in urban environments. However, as much as urban gardening offers numerous benefits, it also brings attention to potential challenges related to the uptake of chemical contaminants by plants. These contaminants can originate from various sources, including industrial activities, traffic emissions, and historical pollution. Understanding the process of plant uptake of chemical contaminants in urban gardening is crucial for assessing the safety and quality of the produce grown in these settings. Plants play a vital role in the environment by interacting with their surroundings and absorbing nutrients necessary for their growth. However, they can also inadvertently absorb and accumulate harmful substances, such as heavy metals, pesticides, and volatile organic compounds (VOCs), present in the soil, water, or air. The uptake of these chemical contaminants can pose risks to both the plants themselves and the individuals who consume them.

The mechanisms by which plants take up and accumulate chemical contaminants are complex and depend on various factors, including the type and concentration of contaminants, the plant species, soil properties, and environmental conditions. Roots are the primary entry point for contaminants, as they absorb water and nutrients from the soil. Contaminants dissolved in soil water can be taken up by the roots and transported through the plant's vascular system to other plant parts, such as leaves, stems, and fruits.

Once inside the plant, contaminants can have detrimental effects on its growth and development. They can interfere with essential physiological processes, disrupt nutrient uptake and metabolism, and even cause visible symptoms of toxicity, such as leaf discoloration, stunted growth, or reduced crop yields. Moreover, some contaminants, such as heavy metals, tend to accumulate in plant tissues over time, leading to long-term exposure risks.

The concern over plant uptake of chemical contaminants in urban gardening is particularly significant due to the proximity of these gardens to potential pollution sources. Urban environments are often characterized by higher levels of air pollution, soil contamination, and water pollutants compared to rural or agricultural areas. These conditions can increase the likelihood of plants absorbing chemical contaminants, highlighting the need for proper management strategies and risk assessments in urban gardening practices.

To mitigate the risks associated with plant uptake of chemical contaminants, various approaches can be employed. These include selecting appropriate plant species that are less prone to contaminant accumulation, implementing soil remediation techniques, employing proper irrigation and watering practices, and adopting organic gardening methods to minimize the use of chemical inputs.

In conclusion, while urban gardening offers numerous benefits, the potential uptake of chemical contaminants by plants remains a significant concern. Understanding the mechanisms of plant uptake and accumulation of contaminants, as well as implementing appropriate mitigation strategies, is crucial for promoting safe and sustainable urban gardening practices. By addressing these challenges, urban gardeners can continue to enjoy the rewards of cultivating their own food while ensuring the health and well-being of themselves and their communities.

2. Summary of Contaminants of Emerging Concern (CECs)

With the growing public concern surrounding the environment and human health, it is imperative to identify the contaminants of emerging concern (CECs) that may be found in any given urban gardening site across the United States (Srikanth et al. 2019). A soil contaminant is defined as an element or chemical present in the soil at a level that could potentially pose a risk to human health. Sources of contamination include that of geogenic (naturally occurring) and anthropogenic (human-driven) origin (Soltani-Gerdefaramarzi et al. 2021).

Risks associated with UA soil contamination include plant uptake of contaminants through the soil and bioaccumulation occurring when humans ingest contaminants from vegetation growing in compromised soil (Rosen 2002). Existing guidelines are commonly intended for the clean-up and remediation of highly contaminated sites (Jennings 2013). Their correlation for the safety of food grown in UA soils is unknown. Most urban soils are formed from different parent materials than natural soils and thus require different parameters for use and management. CECs of urban soil are especially important because anthropogenic activities have increased the soil levels of many elements and chemicals (Table 2). Common anthropogenic sources include pesticides, burning fossil fuels, agricultural practices, etc. (Heinegg et al. 2000).

Table 1. Summary of Contaminants of Emerging Concern (CECs)

Heavy Metals	Persistent Organic Pollutants (POPs)
Arsenic (As)	*Petroleum products*: MAHs, PAHs
Barium (Ba)	*Dioxins*: Polychlorinated dibenzodioxins (PCDDs), Polychlorinated dibenzofurans (PCDFs)
Cadmium (Cd)	*Organochlorine Pesticides (OCPs)*: Chlordane, Dichlorodiphenyltrichloroethane (DDT), Aldrin, Dieldrin
Chromium (Cr)	Polychlorinated Biphenyls (PCBs)
Copper (Cu)	Polybrominated Diphenyl Ethers (PBDEs)
Lead (Pb)	Per- and poly-fluoroalkyl Substances (PFAS)
Mercury (Hg)	
Molybdenum (Mo)	
Nickel (Ni)	
Selenium (Se)	
Zinc (Zn)	

2.1. Trace Elements

Trace elements commonly found in urban soils include heavy metals and metalloids. Heavy metals and metalloids are among the most investigated soil contaminants and their presence in the environment is recognized as a global health problem, making metals such as lead (Pb) a legacy CEC. At high concentrations, they act as systemic toxins that interact with specific biological systems to produce teratogenic, neurotoxic, cardiotoxic, and/or nephrotoxic effects. Metals enter the body via inhalation, ingestion, and dermal routes, where they can be store in both soft and hard tissues (Lupolt et al. 2021). Biological organisms are incapable of degrading metals because of their nonbiodegradable nature and long half-life (Amaral and Rodrigues 2005; Nabulo et al. 2011). They are released into solids from lithogenic (parent material) and anthropogenic sources. Nearly any heavy metal and metalloid can be potentially toxic to soil biota depending upon the concentration and duration of exposure. Regarding their roles in biological systems, heavy metals and metalloids can be classified as essential or nonessential (Table 2).

Essential metals function as protein cofactors in various biological processes and are considered non- toxic when present in trace amounts (Apostoli 2002; Antoine et al. 2012). Nonessential metals have no biological function and are considered toxic in trace amounts (Chang 2000; Nies 1999). Nonessential metals pose a threat to human health because of their ability to hijack cellular transport mechanisms of essential metals (Martinez-Finley et al. 2012). These nonessential metals act as systemic toxins that interact with specific systems to produce teratogenic, neurotoxic, cardiotoxic, and/or nephrotoxic effects (Jaishankar et al. 2014; Järup 2003). Both nonessential and high concentrations of essential metals disrupt metabolic processes by altering the number of homeostatic processes (e.g. antioxidant balance; binding to free sulfhydryl groups; competing for enzyme binding sites, receptors, and transport proteins) (Martinez-Finley et al. 2012).

2.2. Persistent Organic Pollutants (POPs)

Persistent organic pollutants (POPs) are toxic chemicals that bioaccumulate and persist in the environment for long periods of time (CEC 2015). The primary concern surrounding the adverse effects of POPs on environmental and human health is linked to their ability to bioaccumulate and be transferred across species via the food chain (Alharbi et al. 2018). Although most POPs are no longer produced in the U.S., the risk associated with environmental persistence of intentionally and unintentionally produced POPs remains. Intentionally produced POPs include chemicals currently or previously used in agriculture, disease control, manufacturing, or industrial processes. Whereas, unintentionally produced POPs result from some industrial processes and combustion (e.g. burning wastes) (U.S. EPA 2009).

Table 2. Common anthropogenic sources of CECs.

Anthropogenic Source	Contaminant Type	
	Trace Elements	*Persistent Organic Pollutants (POPs)*
Paint (before 1978)	Pb	
High traffic areas	Pb, Zn	PAHs
Treated lumber	As, Cr, Cu	
Burning wastes		PAHs, dioxins
Contaminated manure	Cu, Zn	
Coal production	Mo, S, Se	PAHs, dioxins
Sewage sludge	Cd, Cu, Zn, Pb	
Petroleum refining/spills	Pb	Petroleum products (PAHs, MAHs)
Pesticides	Pb, As, Hg	OCPs
Commercial/industrial site use	Pb, As, Ba, Cd, Cr, Hg, Zn	PAHs, MAHs, PBDEs, PCBs, PFAS

Adapted from Heinegg et al. (2000). Pb: lead; Zn: zinc; As: arsenic; Cr: chromium; Cu: copper; Mo: molybdenum; S: sulfur; Se: selenium; Hg: mercury; Ba: barium; PAHs: polycyclic aromatic hydrocarbons; MAHs: monoaromatic hydrocarbons; OCPs: organochlorine pesticides; PBDEs: polybrominated diphenyl ethers; PCBs: polychlorinated biphenyls; PFAS: per- and polyfluoroalkyl substances.

2.3. State Specific Contaminants of Emerging Concern (CECs)

A list of state specific CECs has been expanded from our first report to provide a more generalized visual representation of chemical contaminants across the U.S. Nationwide data was found to still be limited and further research on the remaining states will produce a more cohesive representation of regional and state specific CECs. This will allow for the identification of geographical trends that may be a useful resource for urban growers. Such trends are anticipated based on the various soil media and terrain that make up the terrestrial systems across the U.S. CECs specific to each state and corresponding EPA region have been identified in Table 6.

Table 6. Regional and State Specific Contaminants of Emerging Concern (CECs)

EPA Region	State Name	State Abbr.	Contaminants of Emerging Concern (CECS) Subtypes	
			Trace Metals	POPs
1	Connecticut	CT	Hg, As, Ba, Cd, Pb	BTEX, Naphthalene, benzo(a)pyrene, PCE, TCE
	Maine	ME	Cd, Pb, Zn, Hg, Ba, Ag	Chlordane, DDT/DDE/DDD, PCBs
	Massachusetts	MA	Pb, Hg	1,4-dioxane, perchlorate, PFAS, PBDEs, PCE, TCE,
	New Hampshire	NH		
	Rhode Island	RI		
	Vermont	VT		
2	New Jersey	NJ		PFNA, PFOA, PFOS
	New York	NY		
3	Delaware	DE		
	Maryland	MD	As, Cr	
	Pennsylvania	PA		
	Virginia	VA		
	West Virginia	WV		
	Washington D.C.	DC		
4	Alabama	AL		
	Florida	FL		Benzo(a)pyrene
	Georgia	GA		
	Kentucky	KY	Pb, As, Hg, Ba	Benzo(a)pyrene, PFAS, PAHs
	Mississippi	MS		
	North Carolina	NC	Pb, As, Ba, Cd, Cr, Hg, Se, Zn	Atrazine, BTEX, benzo(a)pyrene, carbaryl, chlordane, PCDD, PAHs, PERC, PCE, PCB, TCE
	South Carolina	SC		Benzo(a)pyrene
	Tennessee	TN		Benzo(a)pyrene
5	Illinois	IL		

	Indiana	IN		
	Michigan	MI		
	Minnesota	MN	Pb, Cd, As	PAHs, PHCs, BTEX
	Ohio	OH		
	Wisconsin	WI		
6	Arkansas	AR		
	Louisiana	LA		
	New Mexico	NM		
	Oklahoma	OK		
	Texas	TX		
7	Iowa	IA		
	Kansas	KS		
	Missouri	MO		
	Nebraska	NE		
8	Colorado	CO		
	Montana	MT		
	North Dakota	ND		
	South Dakota	SD		
	Utah	NT		
	Wyoming	WY		
9	Arizona	AZ		
	California	CA		
	Hawaii	HI		
	Nevada	NV		
10	Alaska	AK		
	Idaho	ID		
	Oregon	OR		
	Washington	WA		

3. Risk Assessment for Potential Exposure to CECs in Urban Agriculture

3.1. Exposure Routes

Exposure to CECs in urban soils occurs through ingestion, inhalation, and dermal contact. In terms of the three exposure pathways, ingestion mainly occurs through intake of crops, whereas exposure via inhalation and dermal pathways occur through direct interaction/contact with soil (Moradi et al. 2016). This report focuses on the ingestion pathway, under the assumption that it is the main exposure pathway to CECs in urban soils, and therefore having the most significant impact on human health. However, it is important to note that exposures to CECs in urban soils through dermal and inhalation routes do have minor impacts on human health.

3.2. Effects of CECs on Human Health

The presence of CECs in urban soils allows for potential contamination in edible plants and thereby poses risks to human health. Impacts of CECs on human health vary depending on exposure and host factors, such as contaminant type, exposure pathway, exposure concentration, and host characteristics (ATSDR 2005).

3.2.1 Trace Elements

(a) Zinc (Zn)

Human exposure to elevated zinc concentrations greater than the RfD (reference dose) of 0.3 mg/kg-day may result in adverse health effects (U.S. EPA 2005). According to the Agency for Toxic Substances and Disease Registry (2005), documented health effects from zinc exposures include shortness of breath, cough, chest pain, metal fume fever, and death. Acute exposure to elevated doses of zinc most often results in nausea, stomach cramping, vomiting, and/or metal fume fever (ATSDR 2005). Chronic exposure to zinc levels between 150-2,000 mg/day may result in copper deficiency and anemia (Nriagu 2007). While zinc is not considered carcinogenic, excess exposure may still disrupt metabolic processes and result in negative health effects (Nriagu 2007).

(b) Nickel (Ni)

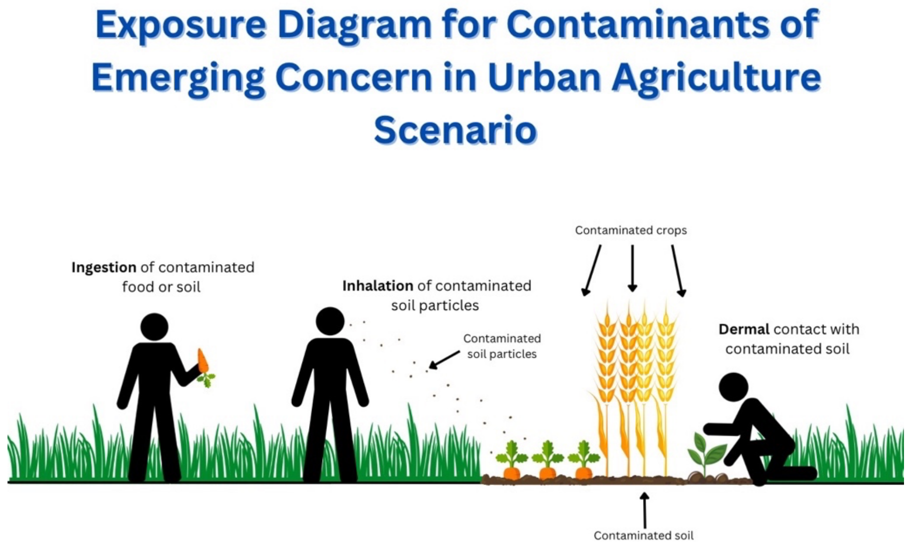

Figure 1. Exposure diagram depicting exposure routes to contaminants of emerging concern in urban agriculture scenarios.

According to the ATSDR (2005), the most common adverse health effect associated with acute nickel exposure is an allergic reaction in the form of contact dermatitis. Exposure to nickel via inhalation can lead to respiratory effects such as asthma attacks, bronchitis, and difficulty breathing depending upon length of exposure (Genchi 2020). Chronic exposure to nickel may result in diseases of the kidney, respiratory system, and cardiovascular system (Zambelli & Ciurli 2013). Certain forms of nickel such as nickel subsulfide and nickel refinery dust are considered carcinogenic, whereas soluble nickel salts are not, though many suggest potential carcinogenicity (Genchi et al. 2020 ; IARC 1990 ; Shen & Zhang 1994).

(c) Copper (Cu)

A reference dose and concentration for copper ingestion and inhalation respectively has not yet been established by the U.S EPA. Exposure to elevated concentrations of copper via oral route can result in damage to gastrointestinal and hepatic systems, kidney failure, and death (ATSDR 2022). Copper is not classified as a human carcinogen according to the U.S. EPA (1988).

(d) Molybdenum (Mo)

Data on molybdenum toxicity in humans is limited. Mild respiratory issues have been observed following molybdenum dust inhalation in workers (ATSDR 2020). Increased molybdenum intake can lead to copper deficiency, elevated uric acid levels, and joint pain/aching (Novotny & Peterson 2018). Molybdenum is not currently classified as a human carcinogen (U.S. EPA 1992).

(e) Selenium (Se)

Acute exposure to elevated levels of selenium via ingestion can result in vomiting, nausea, abdominal pain, and diarrhea, while chronic exposure can lead to more serious health conditions, such as selenosis also referred to as selenium intoxication (ATSDR 2003). This condition may result in hair loss, nail loss, tooth decay, and fatigue (ATSDR 2003). Neurological effects have also been observed in multiple studies following both acute and chronic exposures, including irritability, tremors, decreased mental alertness, and amyotrophic lateral sclerosis (Civil & McDonald 1978 ; Rosenfeld & Beath 1964 ; Sioris et al. 1980). Selenium is not currently considered a carcinogen (U.S. EPA 1991).

(f) Cadmium (Cd)

Cadmium is classified as a probable carcinogen by the U.S. EPA (1989), though a quantitative estimate for carcinogenic risk is only available for inhalation exposure. Vomiting, diarrhea, and stomach irritation have been reported following acute exposure to high concentrations of cadmium (ATSDR 2008). Chronic ingestion of low concentrations of cadmium has been shown to result in kidney disease and decreased bone strength (Genchi et al. 2020).

(g) Lead (Pb)

Most lead exposures in humans occur through ingestion. Chronic ingestion of lead may result in adverse developmental, neurological, reproductive, and hematological effects, including anemia, sperm abnormalities, and decreased IQ (ATSDR 2020). Short term ingestion of lead can cause stomach irritation, kidney damage, neurological disorders, and even death (CDC 2014). According to the U.S. EPA (1988) lead is classified as a probable human carcinogen based on sufficient evidence in animal studies, though human data is not sufficient for classification as a human carcinogen.

(h) Mercury (Hg)

Although mercury is not characterized as a human carcinogen by the U.S. EPA (1995), mercury exposure can result in severe and lasting damage to the kidneys and nervous system. Chronic ingestion of mercury may lead to developmental and neurological disorders such as muscle weakness, loss of sensation, and cognitive dysfunction (ATSDR 2022). Serious health effects observed after acute exposures to mercury are typically from inhalation exposures, as acute exposure through ingestion does not tend to result in severe health effects since mercury is not easily absorbed by the gastrointestinal tract (Park & Zheng 2012). These effects include tremors, memory loss, respiratory distress, and death (Park & Zheng 2012).

(i) Chromium (Cr)

Chromium (VI) or hexavalent chromium exposure via inhalation has resulted in adverse respiratory effects such as bronchitis, asthma, and lung cancer (Alvarez et al. 2021). Due to sufficient evidence of lung cancer in humans following exposure, chromium (VI) is classified as a carcinogen via inhalation exposure, though not via ingestion or dermal exposure (U.S. EPA 1998). Ingestion of chromium may lead to stomach irritation, hepatic abnormalities, cardiovascular complications, and death. Dermal exposure to chromium may lead to skin ulcers and contact dermatitis (ATSDR 2012).

(j) Arsenic (As)

Arsenic is characterized as a human carcinogen via both inhalation and ingestion exposures (U.S. EPA 1995). Acute arsenic exposure via inhalation can result in respiratory irritation, while chronic exposure may lead to more severe respiratory complications, as well as skin discoloration and warts. Exposure to arsenic through ingestion can lead to stomach irritation, hematological abnormalities, cardiovascular complications, and death. Dermal exposure to arsenic has been shown to cause contact dermatitis and swelling (ATSDR 2007).

(k) Barium (Ba)

According to the U.S. EPA (1998), barium and barium compounds are not classified as human carcinogens. The severity of health effects following barium ingestion is dependent upon the characteristics of the barium compound. Some barium compounds are more soluble than others, which allows for greater absorption in the gastrointestinal tract (ATSDR 2007). Acute barium ingestion particularly affects the gastrointestinal and nervous systems, and may result in stomach irritation, muscle weakness, paralysis, and even death (Kravchenko et al. 2014). Data on chronic barium exposure is limited.

3.2.2. Persistent Organic Pollutants (POPs)

3.2.2.1. Petroleum Products

(a) Monocyclic Aromatic Hydrocarbons (MAHs)

The group of chemicals known as benzene, toluene, ethylbenzene, and xylene (often referred to as BTEX) are the most well-known monocyclic aromatic hydrocarbons in terms of environmental contaminants. Exposure effects on human health are similar among the group, with nervous system and neurological effects being the most observed.

(i) Benzene

Benzene is classified by the U.S. EPA (2003) as a known human carcinogen. Short term exposure to the chemical via inhalation can cause severe neurological effects such as tremors, dizziness, unconsciousness, and death. Acute ingestion of benzene at high concentrations may lead to gastrointestinal irritation, convulsion, drowsiness, rapid heart rate, and death. Chronic exposure to low doses of benzene typically results in hematological effects like anemia (ATSDR 2007).

(ii) Toluene

Severe nervous system effects including dizziness, drunken-type actions, and memory loss have been observed following acute toluene inhalation even at low concentrations (ATSDR 2017). Chronic inhalation of toluene has also resulted in hearing loss, color vision loss, and brain damage. Ingesting toluene even at low concentrations can cause renal effects, cardiovascular effects, and acute encephalopathy (Filley et al. 2004). Studies on children exposed to toluene in utero have reported developmental effects and delays (ATSDR 2017) Toluene has not been classified on its carcinogenicity due to limited data (U.S. EPA 2005)

(iii) Ethylbenzene

Inhalation exposure to high concentrations of ethylbenzene can cause similar nervous system effects to toluene, lightheadedness, difficulty breathing, and loss of coordination. (NJDOH 2016). Acute inhalation of ethylbenzene typically leads to throat irritation, difficulty breathing, and dizziness (ATSDR 2010). Ingesting elevated levels of ethylbenzene can result in gastrointestinal irritation, rapid heartbeat, and similar nervous system effects to ethylbenzene inhalation. Death has been observed following inhalation and ingestion of elevated levels of ethylbenzene (CDC 2018). The U.S. EPA does not classify ethylbenzene as a human carcinogen (U.S. EPA 1991).

(iv) Xylene

Headaches, confusion, memory loss, delayed reaction time, and loss of coordination may occur following acute or chronic exposure to elevated levels of xylene (ATSDR 2007). Acute ingestion of xylene can cause gastrointestinal irritation, hepatic effects, renal effects, and death. Throat irritation, nose irritation, and respiratory issues have been observed following large concentrations of xylene were inhaled. Dermal contact with xylene typically results in irritation at the site of contact (ATSDR 2007). Xylene has not been classified on its carcinogenicity due to lack of data (U.S. EPA 2003).

(b) Polycyclic Aromatic Hydrocarbons (PAHs)

Acute ingestion of PAHs can cause gastrointestinal irritation, while chronic ingestion may lead to kidney damage, liver damage, and hematological effects. Contact dermatitis has been observed following acute dermal exposure to PAHs. Potential carcinogenicity of PAHs has been suggested in some studies, though the EPA and IARC have not yet evaluated PAHs (Kim et al. 2013).

3.2.2.2. Dioxins

(a) Polychlorinated dibenzodioxins (PCDDs)

Data on human health effects from PCDDs exposures is severely limited, though exposure to dioxins is generally associated with dermatological effects such as lesions, hyperpigmentation, and chloracne. Liver damage or dysfunction is also observed following dioxin exposure (Mukerjee 1998).

(b) Polychlorinated dibenzofurans (PCDFs)

Most data on exposures to polychlorinated dibenzofurans (PCDFs) is limited to acute exposures. Fatigue, headaches, gastrointestinal irritation, hepatic effects, respiratory irritation, and dermal effects may result following acute ingestion of PCDFs. PCDFs have not yet been assessed for their carcinogenicity by the U.S. EPA or IARC due to lack of data (IARC 1997).

3.2.2.3. Organochlorine Pesticides (OCPs)

Organochlorine pesticides (OCPs) have been banned in the United States and in most countries, although they are still used illegally in some (Jayaraj et al. 2016). The four most notable organochlorine pesticides and their human health effects are evaluated below. The most commonly observed health effects among the group are disorder of the nervous system, gastrointestinal irritation, and carcinogenicity.

(i) Chlordane

Acute ingestion of chlordane in humans typically results in gastrointestinal irritation, headaches, confusion, and tremors. Chronic exposure can lead to more serious neurological effects such as depression, anxiety, and irritability. Ingesting substantial amounts of chlordane may cause convulsions and/or death (ATSDR 2018). Chlordane is classified as a probable human carcinogen according to the U.S. EPA (1998).

(ii) Dichlorodiphenyltrichloroethane (DDT)

In 1988, the U.S. EPA officially classified DDT as a probable human carcinogen. Headaches, seizures, nausea, and vomiting have been reported following acute ingestion of high DDT concentrations (ATSDR 2022). Chronic exposure to DDT can result in increased diabetes risk.

(iii) Aldrin

Aldrin is classified as a probable human carcinogen by the U.S. EPA (1987). Chronic exposure to aldrin at low doses may result in headaches, mood changes, uncontrolled muscle movement, nausea, and vomiting (ATSDR 2022). Acute exposure to high concentrations of aldrin can cause convulsions or death (ATSDR 2022).

(iv) Dieldrin

According to the U.S. EPA (1988), dieldrin is classified as a probable human carcinogen. Effects from dieldrin exposure are similar to those of aldrin exposure, with major adverse effects on the nervous system including muscle convulsions, incoordination, and seizures (National Research Council (US) Committee on Toxicology 1982).

3.2.2.4. Polychlorinated Biphenyls (PCBs)

Most exposure studies are children who were exposed via breast milk or in utero. Amongst these studies, behavioral abnormalities were the main effects observed, including decreased short-term memory, cognitive dysfunction, and motor skill issues (Washington State Department of Health). In 1996 the U.S. EPA classified PCBs as a probable human carcinogen.

3.2.2.5. Polybrominated Diphenyl Ethers (PBDEs)

Studies on PBDEs effects in humans are mostly limited to children, with some studies suggesting neurodevelopment effects such as decreased attention, motor skill impairment, and increased impulsivity in children (ATSDR 2017).

3.2.2.6. Per- and Poly-fluoroalkyl Substances (PFAS)

Research on human health effects of PFAS exposure is still ongoing, though recent studies suggest reproductive, developmental, immunological, cardiovascular, and carcinogenic effects. (U.S. EPA 2023). PFAS are classified as a human carcinogen according to the IARC, though the EPA has not yet classified PFAS. (American Cancer Society 2023).

4. Plant Uptake of Contaminants of Emerging Concern (CECs) in Urban Soils

Soil is one of the primary sinks for chemical contaminants due to plants' tendency to uptake chemicals present in soil. Industrialization has introduced various new types of chemicals that have been proven to have a detrimental effect on urban soil, thus termed contaminants of emerging concern (CECs). The fate of CECs in soil media is highly uncertain because they are subject to volatilization, microbial degradation, and photodegradation (Reddy and Kim, 2015). Environmental factors such as surface runoff, air currents, and soil erosion also play key roles in the fate of CECs in urban soils. The knowledge gaps regarding the exposure impact of CECs on the terrestrial food chain make it imperative to determine their uptake and potential effect on plants.

Urban soil systems differ from their rural counterparts in terms of their physical and chemical properties (Wortman and Lovell 2013). Urban agricultural soils are highly variable chemically and physically at fine geographic scales, reflecting the various management history of individual sites (Beniston and Lal 2012). Consequently, plant uptake findings from rural agricultural soils do not directly apply for risk assessment of urban soil media. When evaluating the environmental fate of chemicals in terrestrial ecosystems, the bioavailability of the chemical and the effects of soil characteristics are both important considerations in determining the potential for intercompartment transfer as well as the bioaccumulation potential of a chemical. Bioavailability of organic compounds in terrestrial environments is complicated by many factors that will also influence the outcome of bioaccumulation tests (Hoke et al. 2014).

The physiochemical properties of CECs have a crucial role in the overall uptake and translocation from soil to plant systems. Transpiration stream concentration factor (TSCF) is defined by Shone and Wood (1974) as “the ratio of chemical concentration in the transpiration stream to the concentration found in an external solution.” TSCF is an important tool in determining the overall uptake of CECs from soil to the xylem of plants (Tanoue et al., 2012; Miller et al., 2016). The TSCF values for hydrophilic compounds have been experimentally proven to be higher than hydrophobic neutral compounds in soybean, zucchini, and squash plants (Garvin et al., 2015). The primary route of uptake for plants is through their roots. Plant uptake and translocation of CECs follows the same general scheme: (1) Uptake from the environment; (2) Root uptake; (3) Translocation within the plant; (4) Accumulation in plant tissues; (5) Metabolism and transformation. Plants serve as a primary vehicle for the transfer of CECs into the food chain. CECs enter plant systems through two key processes: uptake and translocation. Uptake and translocation of pollutants by plants are affected by (i) plant physiology, (ii) soil properties, (iii) environmental factors, and (iv) the physiochemical properties of the pollutants.

(i) *Plant Physiology*

Vascular plant tissue is composed of the xylem and phloem. The xylem is a unidirectional transport system for water and minerals, whereas the phloem is a bidirectional transport system for organic molecules. When water and solutes enter the plant root through the epidermis, organic contaminants in solution either cross the root membranes and transport through the vascular pathways to the aerial tissues or accumulate in the plant roots (Doucette et al. 2017). The accumulation of contaminants in plant roots and edible tissues is measured by root concentration factor (RCF) and fruit concentration factor (FCF) (Doucette et al. 2017). There is a positive correlation between organic pollutant content and lipid content in plant roots (Gao and Zhu 2004). Root uptake of polychlorinated dibenzofurans (PCDD/Fs) from nutrient solution was dominated by lipophilic adsorption, and root accumulation of PCDD/Fs from soil solutions could be predicted by extractable lipid content in plant root (Zhang *et al.* 2009). Most polycyclic aromatic hydrocarbons (PAHs) were detected in plant cell walls which consist mostly of carbohydrate. Therefore, the carbohydrate content of plant cells played a leading role in the uptake of PAHs by plants (Chen *et al.* 2009; Zhang and Zhu 2009). Evidence of varying bioaccumulation of CECs across plants species is presented by their growth, reproduction, occurrence, and survival in the contaminated soil (Doucette et al. 2017). Various plant species can present different toxicity to identical pollutants in the same environmental condition because the mechanisms of elemental uptake by plants are not the same for all plant species. Bryophytes have been used in literature as bioindicators and biomonitors in terrestrial habitats due to their wide range of remarkable anatomical and physiological properties that mirror those of vascular plants (e.g., a plant with roots, stems, leaves) (Doucette et al. 2017).

Table 7. Plant Physiology Factors Affecting Bioconcentration Factor (BCF) of Plants (Christou et al. 2019a).

+	-
Plant genotype (genus & species) e.g., leafy vegetables	Crops with small root systems e.g., succulent plants
Summer growing season	Rainy growing season
Healthy plants	Stressed plants
High plant Kc values	Low plant Kc values
High net irrigation requirements	Low net irrigation requirements
Low lipid content in roots	High lipid content in roots

The majority of studies with regard to CECs uptake examined mostly (a) vegetables (leafy vegetables such as lettuce and cabbage, fruit vegetables such as tomato and cucumber, and root vegetables such as carrot and radish) and (b) cereals and fodder crops (e.g. maize, wheat, alfalfa) (Christou et al. 2019a). Experimental results revealed that the potential for CECs uptake by crop plants decreased in the order of leafy vegetables > root vegetables > cereals and fodder crops > fruit vegetables (Christou et al. 2019a).

(ii) *Soil Properties*

Inherent properties of natural soils such as pH, fertility, organic matter content, and texture can significantly influence the bioavailability of chemicals (Christou et al. 2019a). The importance of soil type was demonstrated by Princz et al. (2014) in an earthworm bioaccumulation study in which uptake of the test chemical in tissue of earthworms exposed in a sandy soil was significantly greater than that in earthworms exposed to the chemical in clay loam soil where organic matter and clay content were significantly higher.

The transfer capacity of organic pollutants in soil is good in acidic or alkaline media but poor in media with intermediate pH (Sithole and Guy 1987). Increased organic matter content of soil decreased the plant uptake of organic pollutants because some organic pollutants (ionized compounds) might be strongly bound to soil organic matter which is a strong anion/cation exchanger (Trapp and McFarlane 1994). Increased organic matter content of soil decreased the plant uptake of organic pollutants because some organic pollutants (ionized compounds) might be strongly bound to soil organic matter which is a strong anion/cation exchanger (Trapp and McFarlane 1994).

Table 8. Soil Properties Affecting CEC Uptake by Plants (Christou et al. 2019a).

+	-
Low levels of organic matter	High levels of organic matter
Sandy soils	Clay or loamy soils
Acidic pH (pH < pKa of CEC)	Basic pH (pH > pKa of CEC)
Aerated soils (aerobic conditions)	Waterlogged soils (anaerobic conditions)

(iii) *Environmental Factors*

Table 9. Environmental Factors Affecting Evapotranspiration (K_c) by Plants (Christou et al. 2019a).

+	-
High temperature	Low temperature
High wind speed	Low wind speed
Low air humidity	High air humidity
Hot/Dry agricultural areas	Cold/Continental agricultural areas
Adequate soil moisture	Drought conditions

Higher temperature coefficients for diffusion processes of organic pollutants can accelerate passive absorption by the plant. On the other hand, temperature rise stimulated transpiration stream rate and enzyme activity of plants (Korte *et al.* 2000). Further literature review would provide useful for this factor to better understand the impact environmental factors have on plant uptake.

(iv) *Physiochemical Properties of Pollutants*

+	-
Low MW	High MW
Hydrophilic	Hydrophobic

The physiochemical properties of CECs play a crucial role in the uptake and translocation from soil to plant systems. Some contaminants are highly stable and therefore less likely to undergo conformational change during interactions that occur during the uptake and translocation processes. The transpiration stream concentration factor (TSCF) is defined by Shone and Wood (1974) as “the ratio of chemical concentration in the transpiration stream to the concentration found in the external solution.” This factor can be utilized as a tool to determine the overall uptake of CEC from soil to the xylem of plants.

Molecular mass of CECs is the leading pollutant- specific physiochemical property influencing the plant uptake process. The uptake and transportation of pollutants in plant phloem and xylem depends upon the size of the molecule (e.g., MW). For example, organic pollutants with small molecule size can easily permeate the membrane and hence, easily come in and go out of the phloem and xylem. On the other hand, organic pollutants with large molecule size have low permeability in membranes and therefore cannot be effectively transported in the phloem (Kvesitadze *et al.* 2015). Compounds with low MW are volatile and can be easily absorbed by roots and foliage. However, high MW pollutants, which are nonvolatile and possess strong hydrophobic properties, can only be absorbed by roots (Kvesitadze et al. 2015). A compounds tendency to dissolve in (hydrophilic) or repel (hydrophobic) water can be linked to a higher/lower TSCF (Chen et al. 2009).

5. Plant Uptake Models

Plant uptake models can provide information on the accumulation of chemicals and their transformation products from soil. However, the scope, complexity, and cost of these studies limits their routine application for assessment of terrestrial bioaccumulation. Various studies have been carried out to identify uptake and translocation mechanisms of CECs by plants. The primary focus of this research surrounds the uptake of CECs by plant roots.

a. *Mechanism of contaminant uptake by plants*

CECs uptake by plants generally follows two main uptake pathways: (i) extracellular uptake and (ii) intracellular uptake. Extracellular uptake depends on the nature of the elements only, as the physiological conditions of the plant have no impact on the rate of uptake. Intracellular uptake is influenced by various aspects of plant metabolism (Cheng et al. 2017). Entry to the cell plasma is determined by affinity for an appropriate carrier, competitive elements, gradients in element concentration, and energy status. Elements located within the cell influence cell metabolism and must be considered when modeling plant uptake. Uptake rates are in general much lower than at the extracellular sites (Cheng et al. 2017).

Studies have shown that contaminants are enriched at the root surface and enter the roots with water. This mechanistic step is in agreeance with previous literature stating that hydrophilic compounds have a higher uptake rate than hydrophobic compounds. CECs penetrate the roots through the cuticle-free cell walls of young root hairs located closely behind the tip of the root. Contaminants then travel to the xylem transport tissue in the root along free intercellular space (apoplastic way) or cells (symplastic way) (Sterling 1994). The cell wall of the root cortex is porous, allowing for CECs to move freely from solution to the interior before they reach the endodermis (Trapp and Mc Farlane 1994). The general approach for examining bioaccumulation of organic chemicals in terrestrial plants includes measuring either root or foliar uptake, depending on the properties of the chemical or the most relevant route of exposure (Hoke et al. 2014). It must be noted that exposure rates may differ depending on consumption of “the root”, “the shoot”, or “the fruit” of any given plant, therefore potentially posing different health risks. Further research in this area would allow for a more thorough risk-based assessment that takes into account the varying plant species and their subsequent edible parts.

b. *Mechanism of contaminant translocation by plants*

Following uptake by plants, pollutants such as POPs are translocated to different parts of the plants (Lin *et al.* 2007). Generally, two kinds of pollutant transport pathways in higher plants have been reported: (i) intracellular and intercellular transport (short distance transport) and (ii) conducting tissue transport (long distance transport) (Taiz and Zeiger 2002). Currently, agreement on a formal mechanistic approach for contaminant translocation by plants is not present in literature. Furthermore, literature focusing specifically on urban soil media was not identified.

6. Remediation of Contaminated Urban Soil

Remediation techniques for contaminated soils can be classified into three major groups: chemical, physical, and biological. Biological remediation techniques along with a synthesis of results from bioremediation studies are the primary focus of this section, as these methods are cost efficient, environmentally friendly, and minimally invasive, making them most suitable for urban agriculture or home gardening (Ghosh et al. 2022). Other potential remediation methods such as thermal treatment, electrokinetics, and soil washing may be better applied to large scale agriculture with additional support from remediation specialists (Azubuike et al. 2016).

a. Bioremediation

Bioremediation is the process by which biological agents are used to remove an environmental pollutant (U.S. EPA 2013). The process of removal may occur through consumption or degradation by the organism. The bioremediation process may also occur by biologically stimulated stabilization of pollutant levels (U.S. EPA 2013). Research shows bioremediation to be a promising solution for soils contaminated with CECs. Moreover, it is less destructive and typically less costly than conventional remediation techniques (Bwapwa 2022).

b. Phytoremediation

Phytoremediation is a bioremediation method which utilizes plant processes to remove or remediate pollutants (U.S. EPA 1999). Phytoremediation can be divided into several different remediation techniques. Phytoextraction, phytodegradation, and phytostabilization are the most applicable soil remediation techniques in terms of CECs and will therefore be the focus of this section (Ali et al. 2013).

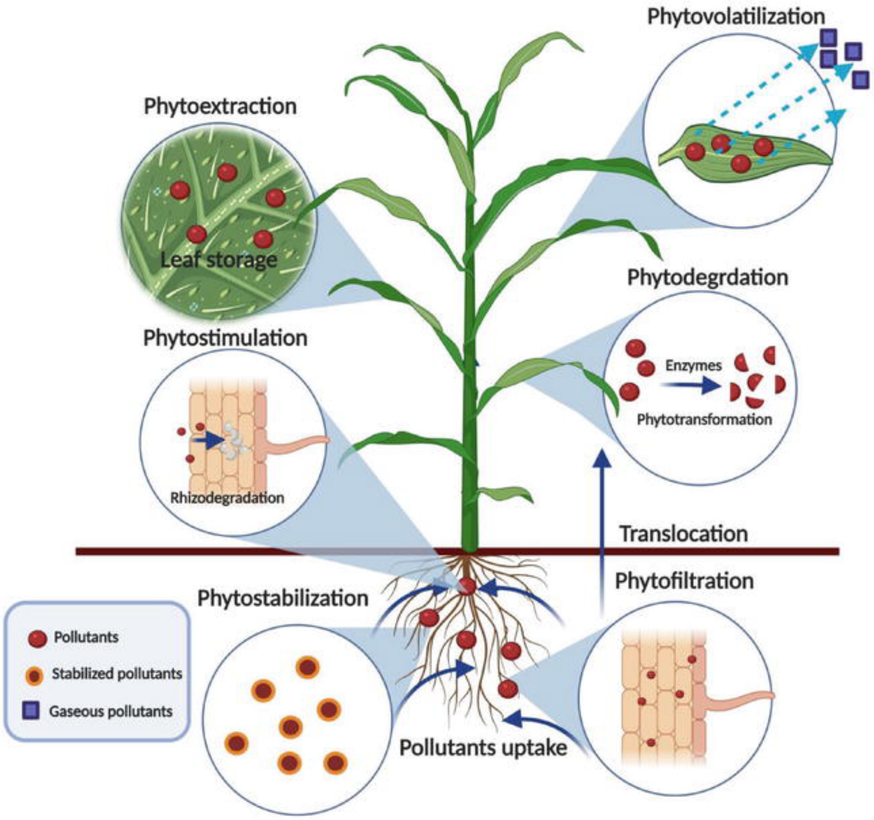

Figure 2. Phytoremediation processes diagram (Krishnasamy et al. 2022)

Phytoextraction is the bioaccumulation of contaminants in plants which are then harvested and properly disposed of or recycled. The method of phytodegradation involves utilizing enzymes produced within the plant to degrade pollutants. Restricting or limiting pollutant transport within plant roots is known as phytostabilization. These three phytoremediation methods are particularly useful in urban agriculture remediation because they best allow for mitigation or removal of CECs in soil (U.S. EPA 1999).

c. Phytoremediation of CECs

1. Trace Elements

Phytoextraction and phytostabilization seem to be the most studied techniques for phytoremediation of trace elements/heavy metals. While phytodegradation is often used in remediation of other contaminants of emerging concern, this method is not feasible for remediation of trace elements since metals cannot be degraded. The most widely used phytoremediation method for heavy metal removal is phytoextraction (Ali et al. 2013). This is mostly due to the low cost and high success rate of the method. Brassica juncea (Indian mustard) is one of the most used plants for phytoextraction of heavy metals, and has shown success in bioaccumulating lead, cadmium, copper, nickel, zinc, chromium, mercury, and selenium (Ali et al. 2013). Metal excluder plants, which accumulate metals in their roots, but limit or prevent metals from reaching their shoot, may be used in phytostabilization of metals (Ali et al. 2013). Examples of metal excluders typically used for phytostabilization include flowering plants, woody plants, and grasses (Mehes-Smith et al. 2013).

2. Dioxins

Phytoremediation of dioxin contaminated soil is an additionally promising remediation method, though mycoremediation shows a higher removal rate than phytoremediation in most studies (Nhung et al. 2022). Crops such as alfalfa, cucumber, pumpkin, and zucchini are frequently utilized in phytoremediation of dioxins (Campanellaand & Paul 2000 ; Huelster et al. 1994 ; Zhang et al. 2009).

3. OCPs

In a 2015 study, Rissato et al. found up to 68% removal of OCPs by the tropical plant species Ricinus communis L. after 66 days via phytoaccumulation. Zucchini, alfalfa, corn, and pumpkin are also known bioaccumulators of OCPs and have been utilized in phytoaccumulation studies (Singh & Singh 2017).

4. PCBs

A 2000 study (Beaudette et al) found that two species of white-rot fungi (Trametes versicolor and Bjerkandera adusta) could degrade up to 65% of polychlorinated biphenyls following a 21-day incubation period. However, like many studies on mycoremediation of POPs, this study was conducted in a laboratory setting, and has yet to be successfully reproduced in the field.

5. PFAS

The process of bioremediating PFAS involves removing a fluorine atom through an oxidation or reduction reaction facilitated by bacteria (Shahsavari et al. 2021). Due to the persistent nature and strength of PFAS in the environment, passive bioremediation techniques like natural attenuation and monitoring are ineffective (Darlington et al. 2018). In terms of phytoremediation as a potential solution to PFAS contamination, phytoextraction seems more promising than phytodegradation, as the strong carbon-fluorine bonds of PFAS make it difficult to break down entirely (Shahsavari et al. 2021). One study by Huff et al. (2020) found that woody and herbaceous plants are highly successful at bioaccumulating PFAS and can be utilized in phytoextraction of PFAS. Lettuce, radish, and alfalfa have also been heavily studied on their ability to bioaccumulate PFAS (Lesmeister et al. 2021). Time is a major issue with PFAS phytoremediation, even with the use of hyperaccumulating PFAS plants, remediation may take multiple decades (Evangelou & Robinson 2022).

d. Limitations of Phytoremediation

Time is a limiting factor in phytoremediation, as the process typically takes several years for complete or even partial remediation of heavy metals in soils (Ali et al. 2013). Additionally, phytoremediation is only useful in sites with low to moderate heavy metal concentrations because plants will not survive in soils with high metal concentrations. (Ali et al. 2013). More research is needed on phytoremediation of trace elements to develop more time-efficient site remediation methods.

e. Mycoremediation

Mycoremediation is the use of fungi to remediate an environmental pollutant. Most fungal mycelia naturally secrete enzymes that degrade lignin and cellulose, which are similar in structure to many persistent organic pollutants, making them successful at degrading certain POPs (Akhtar & Mannan 2020). Mycoremediation may also occur through mechanisms of bioaccumulation or bioconversion of pollutants.

f. Mycoremediation of CECs

1. Petroleum Products

90% biodegradation of PAHs (specifically anthracene, pyrene, and phenanthrene) was achieved after 15 days of incubation in a 2017 study (Moghimi et al) using a strain of fungi known as Trematophoma sp. UTMC 5003.

2. Dioxins

Numerous fungal species have shown success in remediating dioxins in soils. Phlebia radiata strain PL1 has shown very promising results in degrading dioxins, with removal percentages of 100% in multiple studies (Tachibana et al. 2007, Pinedo-Rivilla et al. 2009). Acremonium sp. strain 622, Phanerochaete sordida YK-624, and Cordyceps sinensis strain A also show capabilities of degrading a wide variety of dioxins (Nhung et al. 2022).

3. Trace Elements

Pleurotus ostreatus is a known hyperaccumulator of heavy metals, and has demonstrated the ability to remove manganese, lead, zinc, chromium, nickel, copper, and cobalt from contaminated soils (Vaseem et al. 2017). Aspergillus species has also demonstrated success in removing arsenic, cadmium, and silver from soils via bioaccumulation (Akhtar & Mannan 2020).

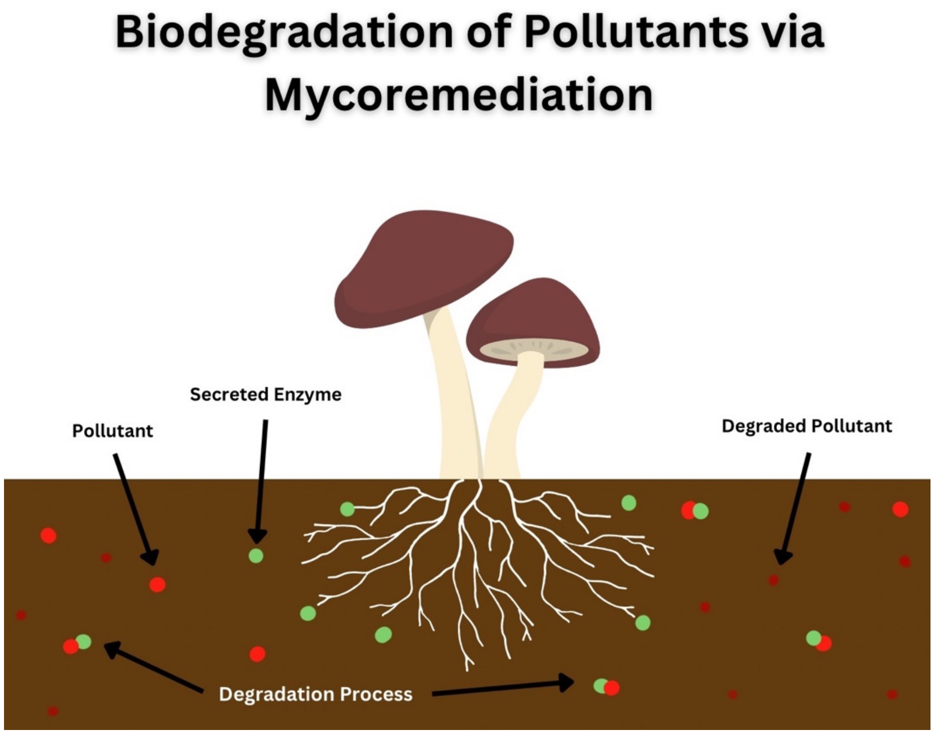

Figure 3. Diagram depicting mycoremediation process. Biodegradation of organic pollutants occurs via enzyme secretions from fungal mycelium.

4. PFAs

As fungi have been shown to degrade persistent organic pollutants such as PAHs, PCBs, and OCPs, it has been suggested that they might also be able to degrade PFAS (Shahsavari et al 2021). However, research on mycoremediation of PFAS is severely limited. Ligninolytic fungi has shown success in degrading PFAS in a small number of lab studies, but similar studies in field environments have not yet been reproduced (Shahsavari et al. 2021). Given the strong degradation capabilities of fungi, with continued research and experimentation, mycoremediation may be a promising solution to remediating PFAS contaminated soils.

e. Limitations of mycoremediation

While mycoremediation seems to be more time efficient than phytoremediation, lack of research is a major limitation for this method. Mycoremediation may provide a more accessible and less expensive solution to CEC pollution in urban agriculture, but continued research is vital to the field.

7. Common Crops Grown in Urban Areas Across the United States

- *Region 1 (Maine, New Hampshire, Massachusetts, Vermont, Rhode Island, Connecticut)*
  - Maine
    - Asparagus, beets, broccoli, brussel sprouts, cabbage, carrots, cauliflower, corn, cucumbers, eggplant, kale, lettuce, okra, onion, potatoes, pumpkin, radish, rhubarb, soybeans, spinach, swiss chard, tomatoes, turnip
  - New Hampshire
    - Artichoke, asparagus, beans, cabbage, cauliflower, cucumbers, eggplant, green beans, kale, lettuce, okra, potatoes, rhubarb, spinach, sweet potatoes, tomatoes, turnip
  - Massachusetts
    - Asparagus, barley, beans, beets, broccoli, brussel sprouts, cabbage, carrots, cauliflower, corn, cucumbers, eggplant, green beans, kale, lettuce, mustard, okra, onions, potatoes, rhubarb, spinach, sweet potatoes, tomatoes, turnips
  - Vermont
    - Artichokes, Beans, Corn, Grapes, Ground Cherries, Nut Trees, Plums, Squash, Sunflowers

  - Rhode Island
    - Beans, beets, cauliflower, corn, cucumbers, eggplant, lettuce, oats, onions, pumpkins, radishes, soybeans, spinach, squash, tomatoes, wheat
  - Connecticut
    - Apple, beans, beets, broccoli, cabbage, carrots, corn, cucumber, green beans, lettuce, peas, radish, salad greens, soy beans, spinach, squash, tomatoes, turnips
- *Region 2 (New York, New Jersey)*
  - New York
    - Asparagus, beets, broccoli, cabbage, carrots, cauliflower, corn, cucumber, eggplant, garlic, green beans, kale, lettuce, okra, onion, peas, potatoes, radish, spinach, strawberry, summer squash, swiss chard, tomatoes
  - New Jersey
    - Asparagus, beans, bell pepper, blueberry, cabbage, carrots, cauliflower, corn, cranberry, cucumber, eggplant, kale, lettuce, okra, onions, peach, pumpkins, radishes, snap peas, spinach, squash, tomatoes
- *Region 3 (Pennsylvania, Delaware, Maryland, Virginia, West Virginia,)*
  - Pennsylvania
    - Asparagus, apple, blueberry, cauliflower, corn, cucumber, eggplant, grapes, green beans, kale, leaf vegetables, lettuce, okra, potatoes, radish, raspberry, root vegetables, squash, strawberry, sweet potatoes, tomatoes
  - Delaware
    - Apple, barley, beans, blackberry, corn, cucumber, green beans, lettuce, lima beans, oats, peaches, potatoes, radish, soybeans, squash, strawberry, sweet potatoes, tomatoes, watermelon, wheat, zucchini
  - Maryland
    - Beans, beets, bell pepper, blueberry, broccoli, cabbage, carrots, cauliflower, corn, cucumber, eggplant, green beans, kale, lettuce, peas, potatoes, pumpkin, radish, spinach, sweet potatoes, tomatoes, turnip, wheat
  - Virginia
    - Apple, asparagus, barley, beans, beets, bell pepper, broccoli, cabbage, carrots, corn, garlic, onion, squash, summer squash, tomatoes, turnips, zucchini
  - West Virginia
    - Asparagus, beets, bok choy, broccoli, brussel sprouts, cabbage, carrots, cauliflower, collard greens, kale, leeks, lettuce, napa cabbage, peas, radish, spinach, onions, swiss chard, turnips

- *Region 4 (Kentucky, Tennessee, North Carolina, South Carolina, Mississippi, Alabama, Georgia, Florida)*
  - Kentucky
    - Asparagus, beans, beets, bell pepper, cabbage, carrots, corn, cucumber, green beans, lettuce, oats, okra, radish, rhubarb, spinach, squash, sweet potatoes, tomatoes, turnips
  - Tennessee
    - Apple, asparagus, beans, bell pepper , broccoli, cabbage, carrot, cauliflower, corn, cucumbers, eggplant, kale, lettuce , okra, potatoes, radish, rhubarb, snow peas, spinach, squash, tomatoes, turnips
  - North Carolina
    - Asparagus, beans, bell pepper, broccoli, cabbage, carrots, cauliflower, corn, cucumbers, eggplant, kale, lettuce, okra, onion, peas, potatoes, pumpkins, radish, spinach, sweet potatoes, tomatoes, watermelon, wheat
  - South Carolina
    - Asparagus, beans, beets , bell pepper, broccoli, cabbage, carrots, corn, cucumber, eggplant, green beans, kale, lettuce, oats, okra, onion, pumpkins, radish, spinach, sweet potatoes, tomatoes, watermelon, wheat
  - Mississippi
    - Beans, beets, cabbage, carrots, corn, cucumbers, muskmelon, okra, radish, spinach, summer squash, sweet potatoes, tomatoes, turnips
  - Alabama
    - Apples, asparagus, beans, beets, broccoli, cabbage, carrots, cauliflower, collards, corn, cucumbers, eggplant, green beans, kale, lettuce, okra, onion, pumpkins, radish, spinach, sweet potatoes, tomatoes, turnips
  - Georgia
    - Beans, beets, bell pepper, broccoli, cabbage, carrots, cauliflower, collards, corn, cucumbers, eggplant, green beans, lettuce, okra, onion, peas, pumpkins, radish, spinach, sweet potatoes, tomatoes, watermelon, wheat
  - Florida
    - Beans, beets, bell pepper, blueberry, broccoli, cabbage, carrot, cauliflower, citrus, collard, corn, cucumbers, kale, lettuce, okra, onions, potatoes, radish, snap peas, spinach, strawberry, tomatoes, watermelon

- *Region 5 (Ohio, Michigan, Indiana, Illinois, Wisconsin, Minnesota)*
    - Ohio
        - Asparagus, beans, beets, broccoli, cabbage, carrots, cauliflower, corn, cucumber, eggplant, green beans, kale, lettuce, okra, onions, peas, radish, spinach, squash, summer squash, swiss chard, tomatoes
    - Michigan
        - Apple, asparagus, beans, beets, bell pepper, blueberry, broccoli, cabbage, carrots, cauliflower, cherry, corn, cucumbers, green beans, lettuce, onion, potatoes, radish, raspberry, spinach, squash, tomatoes, zucchini
    - Indiana
        - Apples , beets, blueberry, cabbage, cauliflower, corn, cucumber, lettuce, lima beans, mustard greens, onion, potatoes, pumpkins, radishes, soybeans, squash, tomatoes, turnip, watermelon
    - Illinois
        - Apple, asparagus, cabbage, carrots, cauliflower, corn, cucumber, lettuce, oats, okra, pumpkins, radish, snow peas, soybeans, spinach, tomatoes, wheat
    - Wisconsin
        - Apples, asparagus, barley, broccoli, cabbage, carrots, cauliflower, cherry, cucumber, lettuce, potatoes, radish, raspberry, summer squash, sweet potatoes, turnips, winter squash, zucchini
    - Minnesota
        - Apple, asparagus, beans, beets, broccoli, brussel sprouts, cabbage, carrots, cauliflower, corn, cucumber, eggplant, kale, lettuce, okra, onion, peas, pumpkin, radish, spinach, sweet potatoes, tomatoes, turnip
- *Region 6 (Louisiana, Arkansas, Oklahoma, Texas, New Mexico)*
    - Louisiana
        - Beans, bell pepper, brussel sprouts, cabbage, cauliflower, corn, cucumbers, eggplant, lettuce, lima beans, okra, onion, peanuts, pumpkin, snap peas, soybeans, squash, strawberry, sweet potatoes, tomatoes
    - Arkansas
        - Asparagus, broccoli, cabbage, carrots, collards, corn, cucumber, eggplant, green beans, kale, lettuce, okra, peanuts, peas, potatoes, pumpkin, rice, soybeans, squash, tomatoes, turnips, wheat
    - Oklahoma
        - Asparagus, beans, beets, broccoli, cabbage, carrot, cauliflower, chard, corn, cucumber, eggplant, garlic, green beans, kale, lettuce, okra, onion, peas, potatoes, pumpkin, radish, spinach, sweet potatoes, tomatoes
    - Texas
        - Artichoke, asparagus, beets, bell pepper, broccoli, cabbage, carrots, cauliflower, corn, cucumber, eggplant, garlic, lettuce, okra, onion, potatoes, pumpkins, radish, spinach, sweet potatoes, tomatoes, turnips, wheat
    - New Mexico
        - Asparagus, beets, broccoli, cabbage, carrots, cauliflower, chard, chiles, corn, cucumbers, eggplant, garlic, kale, lettuce, okra, onion, peas, potatoes, pumpkins, radish, snap peas, spinach, sweet potatoes, tomatoes
- *Region 7 (Nebraska, Kansas, Missouri, Iowa)*
    - Nebraska
        - Asparagus, beets, bell pepper, broccoli, cabbage, carrots, cauliflower, corn, eggplant, kale, lettuce, oats, okra, onions, peas, potatoes, radish, snap beans, sorghum, soybeans, spinach, tomatoes, wheat
    - Kansas
        - Arugula, beans, beets, bok choy, broccoli, brussel sprouts, cabbage, carrots, cauliflower, cucumbers, eggplant, kale, lettuce, okra, peppers, potatoes, radishes, spinach, summer squash, sweet potatoes, tomatoes, turnips
    - Missouri
        - Asparagus, beans, beets, bell pepper, broccoli, cabbage, carrots, corn, cucumber, eggplant, kale, lettuce, okra, onion, peas, potatoes, radish, spinach, sweet potato, swiss chard, tomatoes, wheat
    - Iowa
        - Apple, asparagus, beans, broccoli, brussel sprouts, cabbage, carrots, cauliflower, corn, cucumber, kale, lettuce, okra, onion, peas, potatoes, pumpkin, radish, snap beans, spinach, squash, sweet potatoes, swiss chard, tomatoes
- *Region 8 (Montana, North Dakoda, South Dakoda, Wyoming, Utah, Colorado)*
    - Montana
        - Beans, beets, broccoli, cabbage, carrots, cauliflower, cucumbers, garlic, onions, peas, peppers, potatoes, tomatoes, winter squash, zucchini
    - North Dakota
        - Apples, asparagus, cabbage, corn, cucumber, kale, lentils, lettuce, oats, soybeans, sunflowers, tomatoes, wheat

    - South Dakota
        - Asparagus, beans, bell pepper, cabbage, celery, corn, cucumbers, eggplant, kale, lettuce, oats, onion, potatoes, pumpkin, radishes, snap peas, soybeans, sunflowers, tomatoes, wheat, winter squash
    - Wyoming
        - Apples, asparagus, barley, beets, broccoli, cabbage, cauliflower, corn, green beans, lettuce, oats, onions, peas, pumpkins, radishes, rhubarb, soybeans, spinach, squash, tomatoes, turnips, wheat
    - Utah
        - Asparagus, beans, beets, broccoli, cabbage, carrots, cauliflower, celery, corn, cucumber, eggplant, green beans, kale, lettuce, okra, onion, peas, potatoes, radishes, spinach, swiss chard, tomatoes, watermelon
    - Colorado
        - Apple, beans, beets, broccoli, cabbage, carrots, cauliflower, corn, cucumbers, eggplant, green beans, kale, lettuce, onion, peas, potatoes, pumpkins, radishes, spinach, strawberry, sweet potatoes, swiss chard, tomatoes, turnip
- *Region 9 (Arizona, Nevada, California, Hawaii)*
    - Arizona
        - Beans, beets, bell pepper, broccoli, cabbage, carrots, cauliflower, corn, cucumber, eggplant, green beans, kale, lettuce, okra, onions, peas, potatoes, pumpkins, radish, spinach, sweet potatoes, tomatoes, watermelon
    - Nevada
        - Beets, broccoli, carrots, cauliflower, celery, corn, cucumber, eggplant, kale, lettuce, muskmelon, okra, onion, peanuts, peppers, potatoes, pumpkins, radishes, squash, sweet potatoes, tomatoes, watermelon
    - California
        - Almond, artichoke, avocado, beans, beets, bell pepper, broccoli, carrots, citrus, corn, cucumbers, eggplant, garlic, lettuce, muskmelon, okra, onion, radish, strawberry, summer squash, tomatoes, zucchini
    - Hawaii
        - Avocado, banana, basil, bok choy, cabbage, carrots, collards, corn, cucumber, eggplant, lettuce, okra, onion, papaya, pineapple, potatoes, pumpkins, radish, spinach, squash, summer squash, sweet potatoes, taro, tomatoes
- *Region 10 (Alaska, Washington, Oregon, Idaho)*
    - Alaska
        - Apple, beans, cabbage, carrots, cauliflower, cucumbers, lettuce, onions, potatoes, pumpkin, radishes, spinach, summer squash, swiss chard, tomatoes, turnips, zucchini
    - Washington
        - Apple, artichokes, asparagus, beans, cabbage, carrots, cauliflower, corn, cornsalad, cucumbers, eggplant, mustard greens, onion, potatoes, pumpkins, radishes, raspberry, spinach, squash, summer squash, swiss chard, tomatoes
    - Oregon
        - Apples, artichoke, asparagus, beans, beets, blueberry, broccoli, brussel sprouts, cabbage, carrots, cherry, corn, cucumber, garlic, greens, lettuce, okra, onion, radishes, tomatoes, wheat
    - Idaho
        - Apple, asparagus, barley, beans, beets, bell pepper, blueberry, broccoli, cabbage, carrots, cauliflower, corn, cucumber, eggplant, lettuce, okra, onions, peas, potatoes, radish, strawberry, string beans, tomatoes, turnips

7.1. Regional Trends

- Region 1 (Maine, New Hampshire, Massachusetts, Vermont, Rhode Island, Connecticut)
    - It can be seen that there are regional trends for common plants within this region, other than a few different crops specific to individual states. This is most likely due to these states being in hardiness zones 4 and 5, making their weather similar across all of the region. The most common crops across the region are beans, corn, cucumbers, lettuce, spinach, and tomatoes. All of these crops are seen in 5 out of the 6 states within Region 1.
- Region 2 (New York, New Jersey)
    - It can be seen that there are regional trends for common plants within this region, other than a few different crops specific to individual states. This is most likely due to these states being in hardiness zone 5, making their weather similar across all of the region. The most common crops across the region are asparagus, cabbage, carrots, cauliflower, corn, cucumber, eggplant, kale, lettuce, okra, onion, radish, spinach, tomatoes. All of these crops are commonly planted in both states in Region 2.
- Region 3 (Pennsylvania, Delaware, Maryland, Virginia, West Virginia,)
    - It can be seen that there are regional trends for common plants within this region, other than a few different crops specific to individual states. This is most likely due to Pennsylvania, Delaware, Maryland, and West Virginia being within the hardiness zones 4 and 5. Virginia falls within the hardiness zones 6, and 7, which

    - makes its weather slightly warmer than other states in the region. The most common crops across the region are corn, lettuce, radish, tomatoes. All of which were seen in 4 out of 5 states within the region.
- Region 4 (Kentucky, Tennessee, North Carolina, South Carolina, Mississippi, Alabama, Georgia, Florida)
    - It can be seen that there are regional trends for common plants within this region, other than a few different crops specific to individual states. This region is spread across zones 5, 6, 7, 8, 9, and 10. The most common crops across the region that occur in all eight states in this region are beans, cabbage, carrots, corn, cucumbers, okra, radish, spinach, and tomatoes. Common crops that occur in all but one state in this region are lettuce. Common crops that occur in all but two states in this region are beets, bell peppers, broccoli, and sweet potatoes.
- Region 5 (Ohio, Michigan, Indiana, Illinois, Wisconsin, Minnesota)
    - It can be seen that there are regional trends for common plants within this region, other than a few different crops specific to individual states. This is most likely due to Ohio, Indiana, and Illinois being located in hardiness zones 5 and 6. Michigan and Wisconsin fall within the hardiness zones 3, 4, and 5, which makes its weather slightly cooler than other states in the region and Minnesota falls within 3 and 4. The most common crops across the region are cabbage, cauliflower, cucumber, lettuce, and radish (seen in all 6 states within the region) as well as apples, asparagus, carrots, corn, and tomatoes (seen in 5 out of 6 states in this region).
- Region 6 (Louisiana, Arkansas, Oklahoma, Texas, New Mexico)
    - It can be seen that there are regional trends for common plants within this region, other than a few different crops specific to individual states. This is most likely due to Louisiana being in hardiness regions 8 and 9, which makes its weather slightly warmer than other states in the region. Arkansas, and New Mexico fall within regions 6, 7 and 8. Oklahoma falls within regions 6 and 7 and Texas falls within regions 6, 7, 8, and 9. The most common crops across the region are cabbage, corn, cucumber, eggplant, lettuce, okra, pumpkins, and tomatoes (seen in all 5 states within the region) as well as carrots, cauliflower, onion, sweet potatoes, and potatoes (seen in 4 out of 5 states in this region).
- Region 7 (Nebraska, Kansas, Missouri, Iowa)
    - It can be seen that there are regional trends for common plants within this region, other than a few different crops specific to individual states. This is most likely due to Nebraska and Iowa being in hardiness regions 4 and 5, which makes its weather slightly cooler than other states in the region. Missouri and Kansas fall within regions 5 and 6, making their weather warmer than other states within this region. The most common crops across the region are broccoli, cabbage, carrots, kale, lettuce, okra, potatoes, radishes, spinach, and tomatoes (seen in all 4 states within the region) as well as asparagus, beets, beans, cauliflower, corn, eggplant, cucumber, onion, peas, and sweet potatoes (seen in 3 out of 4 states in this region).
- Region 8 (Montana, North Dakoda, South Dakoda, Wyoming, Utah, Colorado)
    - It can be seen that there are regional trends for common plants within this region, other than a few different crops specific to individual states. This is most likely due to Montana and North Dakota being in hardiness regions 3 and 4, which makes its weather slightly cooler than other states in the region. Wyoming, South Dakota, and Colorado fall within regions 3, 4, and 5. Utah falls within regions 5, 6, and 7, making its weather warmer than other states in this region. The most common crops across the region are cabbage and tomatoes (seen in all 6 states within the region) as well as cucumber, corn, lettuce, and onion (seen in 5 out of 6 states in this region).
- Region 9 (Arizona, Nevada, California, Hawaii)
    - It can be seen that there are regional trends for common plants within this region, other than a few different crops specific to individual states. This is most likely due to Arizona and Nevada being in hardiness regions 5, 6, 7, 8, and 9. California falls within regions 5, 6, 7, 8, 9, and 10. Hawaii falls within regions 10 and 11, making its weather warmer than other states in this region. The most common crops across the region are carrots, corn, cucumber, eggplant, lettuce, okra, onion, radishes, and tomatoes (seen in all 4 states within the region) as well as beets, broccoli, potatoes, pumpkins, and sweet potatoes (seen in 3 out of 4 states in this region).
- Region 10 (Alaska, Washington, Oregon, Idaho)
    - It can be seen that there are regional trends for common plants within this region, other than a few different crops specific to individual states. This is most likely due to Alaska being in hardiness regions 1, 2, 3, 4, 5, 6, and 7, making its weather cooler than other states in this region. Washington falls within regions 5, 6, 7, and 8. Oregon falls within regions 4, 5, 6, 7, 8, and 9. Idaho falls within regions 3, 4, 5, and 6. The most common crops across the region are apples, beans, cabbage, carrots, cucumber, onions, tomatoes, and radishes(seen in all 4 states within the region) as well as asparagus, corn, potatoes, lettuce, and cauliflower (seen in 3 out of 4 states in this region).

8. Guidance for Urban Growers

8.1. Best Practices

(a) Researching the areas in which you will be gardening (looking for any agricultural work, industrial use, or anything that raises the chances of CECs presence in the area). Locate places that are away from old painted buildings, factories, or heavily trafficked areas due to the increased risk of a higher presence of CECs (EPA 2011).

(b) Getting your soil tested: sending off a sample to a state university or privately run lab will tell you ome of the trace elements and persistent organic pollutants (POPs) that could be present in your soil (EPA 2011).

(c) Research your pesticides and fertilizers for any concerning chemicals: make sure to look up if there are any documented issues that state that the certain supplier of the fertilizer or pesticides contain CECs (EPA 2011).

(d) When in doubt on if the levels of CECs are within safe limits, grow your plants in pots or raised gardens. Building raised beds and growing plants in containers is the most common way to reduce the chances of coming into contact with contaminants in urban gardens. These gardening techniques are preferred because the clean soil and organic matter used to build the raised gardening beds creates a physical barrier between the gardeners/plants and possible contamination in the ground soils. Raised beds can be built for permanent or seasonal use (EPA 2011).

(e) Research what plants uptake and translocate CECs more than others. In general, plants that produce fruiting bodies (i.e. tomatoes, squash, apples, pears, and berries) are most appropriate for growing in potentially contaminated soil. Root and tuber crops (i.e. carrots, potatoes, and onions) are often the least appropriate plants to grow in potentially contaminated soil because the edible portions of the crops are in direct contact with the soil. Vegetables with large outer leaves (i.e. cabbage, lettuce, and collard greens) are easily contaminated by dust and soil splash back, so careful washing of these plants is necessary (EPA 2011).

(f) Use soil amendments to stabilize contaminants in soil: adding a thick layer of organic matter to your soil provides a physical barrier to contamination. Soil amendments have also been used to bind contaminants so that they are no longer mobile or bioavailable. Soil amendments improve the overall soil quality for growing plants and are a good addition to any soil (EPA 2011).

(g) Remove all contaminated soil and replace it with clean soil. Make sure the replacement soil is clean by asking the supplier for proof that the soil was tested and reported contaminant-free (EPA 2011).

(h) Use phytotechnologies: These include plants to extract, degrade, contain, or immobilize contaminants in soil. However, using phytotechnologies to clean up contaminants can take many years, is not effective for every contaminants, and generally requires special handling for the disposal of plants used (EPA 2011).

8.2. Soil Testing

(a) Trace elements

Testing for trace elements and metalloid presence in soil can be done through a few different methods. Commercially sold kits are available for purchase which allow for testing soil samples at home. Another option for testing for trace elements is to contact your local state university and see if they have an agricultural program and if they accept soil samples to test for certain contaminants. This is done by labs using reagents (specific types depend on what is suspected in the soil as well as what that specific lab decides to use for their reagents) to extract and quantify the levels of trace elements that are present in the soil sample. Labs may also use Inductively Coupled Plasma-Mass Spectroscopy (ICP-MS). ICP is an analytical technique used to measure and identify elements within a sample matrix based on the ionization of the elements within the sample. Mass Spectrometer (MS) separates the ions out by their mass-to-charge ratio after going through the ICP, and the detector counts the number of selected ions per second which allows the instrument to determine the concentration of each chosen element (OHSU, 2023). Labs may also use Inductively Coupled Plasma Optical Emission spectroscopy (ICP-OES), which is an analytical technique used to determine how much of certain elements are in a sample (Agilent, 2023).

(b) Persistent Organic Pollutants (POPs)

Testing for persistent organic pollutants can be done by sending soil samples to specific labs that can test for these kinds of pollutants. This can be done through a few different methods. The first is the use of fluorescence to characteristic fluorescence spectra emitted by the fluorescent groups of large organic compounds in petroleum hydrocarbons, benzene in polycyclic aromatic hydrocarbons, and organophosphorus in pesticides under the action of laser for quantitative analysis of contaminant identification. Gas Chromatography-Mass Spectroscopy (GC-MS) is another method that is used for detecting volatile and semi-volatile organics. This is done by dissolving the soil sample using reagents which is then put through a capillary column that then separates the molecules of the sample by how long it takes for the molecules to travel through the column of the GC-MS. Different molecules will come off of the column at different times depending on their size and composition. The molecules then travel to the mass spectrometer of the GC-MS where they are captured, ionized, accelerated, deflected, and detected individually. This is done by the mass spectrometer breaking each molecule that was vaporized by the gas chromatographer into ionized fragments and then detecting the fragments of the molecules by using their mass to charge ratio.

Liquid Chromatography-Mass Spectroscopy (LC-MS) is a very similar method to GC-MS in the way that is analyzes samples. One of the key differences is the mobile phases of the machines. The mobile phase of LC-MS is a liquid while GC-MS has a gas mobile phase. It is also seen that the LC-MS has a higher sensitivity in comparison to the GC-MS (Scherbaum E. 2008). High Performance Liquid Chromatography (HPLC) is a technique in analytical chemistry used to separate, identify, and quantify each component in a mixture. It relies on pumps to pass a pressurized liquid solvent containing the sample mixture through a column filled with a solid adsorbent material. Each component in the sample interacts slightly differently with the adsorbent material, causing different flow rates for the different components and leading to the separation of the components as they flow out of the column. Ion Chromatography-Mass Spectroscopy (IC-MS) can be used to separate, identify, and quantify a very wide range of ionizable compounds in complex samples, including those from inorganic, organic, environmental, and biological origins (ACS 2023).

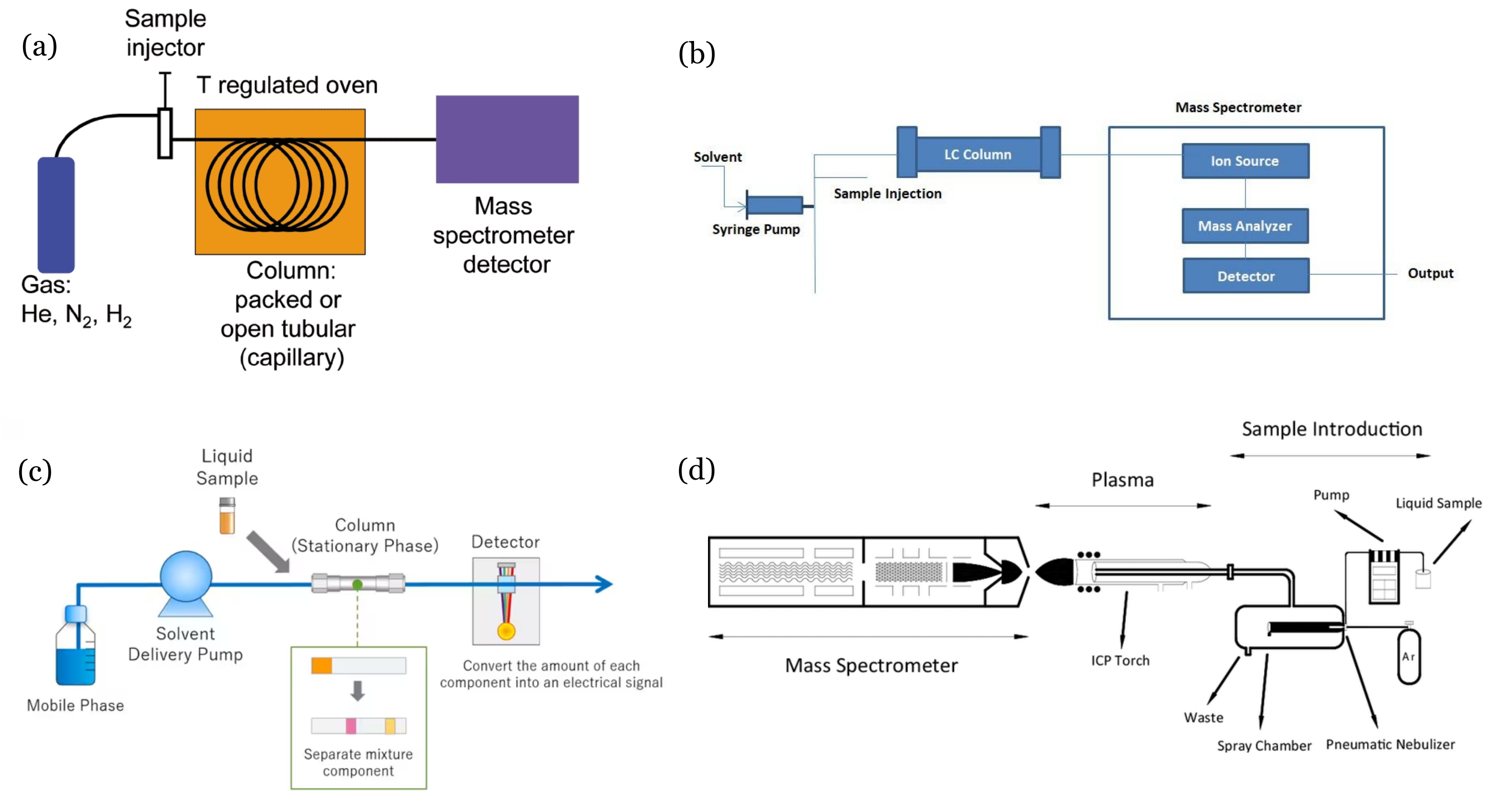

Figure 4. Simple schematics for (a) GC-MS; (b) LC-MS; (c) HPLC; (d) IC-MS

1. Research Gaps and Concluding Remarks

Data gaps on contaminated lands stem from a variety of factors including the multi-jurisdictional responsibilities for identifying, managing, and cleaning up contaminated risk sites (U.S. EPA 2017). The range of contamination at sites varies along with the range of contaminated sites likely to be proposed for food production or crop cultivation. There has been limited effort to establish a baseline or screening standards for sites oriented for food production or urban agriculture beyond past EPA projects focused on examining urban agriculture from the lens of contaminated sites cleanup or risk-based cleanup standards. Along with the U.S. EPA, other various state and/or federal agencies with authority to protect food supply, agricultural resources, and public health may have key roles to play in delineating and developing baseline standards for food production.

In addition, root uptake and reactive transport are plant- and soil- dependent, making it difficult to generalize results. Concern over the release of a chemical to the environment must consider the toxicity of the chemical, the amount and mode (continuous, intermittent) of release, the environmental compartment to which the chemical is released (soil, atmosphere, water), and fate processes that may ameliorate the potential for exposure or transform the compound to a more a less toxic form (Hoke et al. 2014). Fate processes in terrestrial ecosystems include abiotic and biotic processes (e.g., hydrolysis, photolysis, biodegradation, soil adsorption and mobility, volatilization from water or soil) (Hoke et al.

2014). Future literature research on the impact of these fate processes on the uptake, translocation, bioaccumulation, and bioavailability of CECs in urban soils would provide valuable resources for urban growers.

Another limitation found is that soil testing for contaminants appears to be rare in urban agriculture. Soil testing for agronomic parameters such as pH, organic matter, and cation exchange is commonly done in land grant university soil testing labs. Bridging soil testing practices and disciplines of environmental science and agriculture is of utter importance to better integrate testing for environmental contaminants ubiquitous in urban environments. This has proved it difficult to provide growers with national or regional specific concentration factor guidelines for possible risk associated with contaminant exposure through produce grown in urban gardens.

The uptake of CECs by important crop plants, such as fruit trees, is not yet sufficiently evaluated (to our findings). Fruit trees, such as citrus, bananas, apple and other fruit bearing trees, have high evapotranspiration rates, which may render them as plants with moderate to high potential for CECs uptake (similar to that of fruit vegetables) (Hoke et al. 2014). Moreover, further research on the quantification of the examined CECs (including their metabolites) in both the edible parts of the examined plants and in the growing medium is of high importance. This specific data gap is in part due to the difficulty in finding state specific plant uptake models on both an industrial and urban agricultural scale. The continuation of this literature review will allow for a deeper understanding of the potential of urban crop plants to uptake and accumulate CECs, and consequently the assessment of the risk from the consumption of agricultural products grown in urban soils.

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