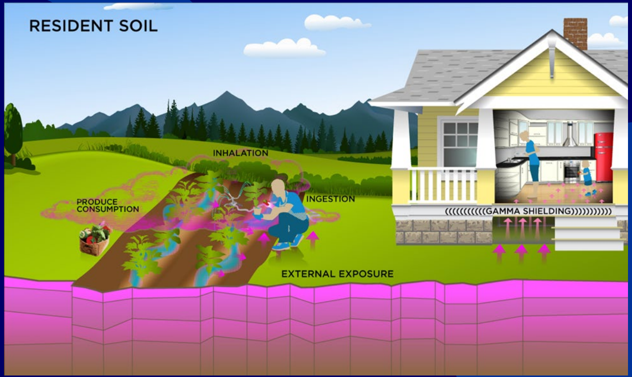
Evaluating Plant Uptake of Chemical Contaminants in Crops Grown Near Urban Gardening Sites for Human Health Risk Assessment

Sponsors of the Virtual Student Federal Service Internships

- Stuart Walker, Lisa Raterink and Michele Burgess, U.S. Environmental Protection Agency, Office of Superfund Remediation and Technology Innovation (OSRTI), Assessment and Remediation Division (ARD), Science Policy Branch
- Jon Richards, U.S. Environmental Protection Agency, Superfund Division Restoration & Site Evaluation Branch, Region 4

Purpose

- Phase 3 of developing a quantitative approach towards establishing regional screening levels for chemicals for gardening scenarios
  - Comparison of Risk Assessment Parameters for Homegrown Produce in Various Models (epa.gov)
  - (https://www.clu-in.org/conf/tio/Plant-Uptake-Pathways_121922/default.cfm?expand=1#tabs-4)
- Identified data gap
  - Uptake of chemicals in plants



Evaluating Food Consumption by Humans in State Models for Risk Assessments of Contaminated sites

The objective of the project is to obtain information that would be useful for evaluating potential updates to EPA's methods for risk assessment at Superfund sites by evaluating how state models address consumption by humans of food in gardening, farming, and hunting scenarios

Evaluate the uptake of chemical contaminants in edible vegetables, fruit, and herbs.

The project would involve research concerning the consumption of edible vegetables, fruit and herbs grown at Superfund sites. Personal and community gardens benefits the property and neighborhood by connecting cultures and encourage healthy eating habits while teaching useful skills. EPA receives numerous requests from communities near Superfund sites regarding the safety of eating vegetables, fruits and herbs grown in those soils. Guidance to assist health assessors and EPA risk assessors in answering those frequently asked questions. It is critical that better information regarding soil bioavailability and plant uptake be incorporated into Superfund human health risk assessment.

State Risk Assessor Questions

1)Are there currently any state-specific transfer models for chemical contaminants involved in plant uptake?

1a) If there are transfer models, what are their strengths and weaknesses?

1b) Are they data driven? Or what assumptions go into their creation?

1c) Are they public? Peer reviewed?

2) Is there a list of known contaminants involved in plant uptake for the state level?

2b) Are you aware of any federal sources (e.g., USDA, etc.)?

3) What database/s would you recommend we use for identifying patterns in rate of uptake for the contaminants?

4) Is there any specific way plants/contaminants are grouped within state models?

5) Is there any priority system within models for the contaminants?

6) Is aggregate uptake of contaminants with similar toxicity mechanisms taken into account?

7) Have you addressed irrigation of gardens or food crops with contaminated water?

7a) Does it depend on media such as soil and/or water or other parameters (e.g., concentration of contaminant in water) to determine if it is acceptable?

8) Are there contaminant- or class-specific models? Are the models comprehensive models?

9) Are there currently any state-specific transfer models for chemical contaminants involved in how much soil, or its mass, adheres to the plant surface?

EPA-US-69 Report

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

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Project Description – 1st Year Report

"Comparison of Risk Assessment Parameters for Homegrown Produce in Various Models" by EPA intern Amanda Balogh

- https://semspub.epa.gov/work/HQ/100002896.pdf

Objective:

- Evaluate the homegrown produce portion of several government issued international models for assessing the risks from chemicals at contaminated sites.
- The report focused on three models with information on how to conduct site-specific chemical risk assessments that include the human consumption of homegrown produce:
  - the Contaminated Land Exposure Assessment (CLEA) model from the United Kingdom's Environment Agency
  - the S-Risk model from Belgium
  - the CSOIL model from the Netherlands

Project Description – 2nd Year Report

"Evaluating Plant Uptake Pathways of Chemical Contaminants in State Models for Risk Assessments of Contaminated Sites"

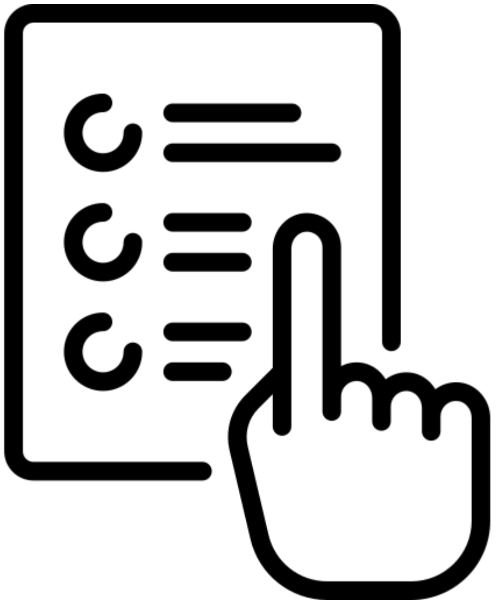
Objective:

- Evaluate current state models and parameters used in assessing the plant uptake pathways of chemical contaminants found in urban agriculture (UA) scenarios.
- Identify food exposure risks associated with contaminated urban sites.

Purpose:

- EPA receives numerous requests from communities near Superfund sites regarding the safety of eating vegetables, fruits and herbs grown in those soils.
- Guidance to assist health assessors and EPA risk assessors in answering those frequently asked questions.
- It is critical that better information regarding soil bioavailability and plant uptake be incorporated into Superfund human health risk assessment.

Poll Time!

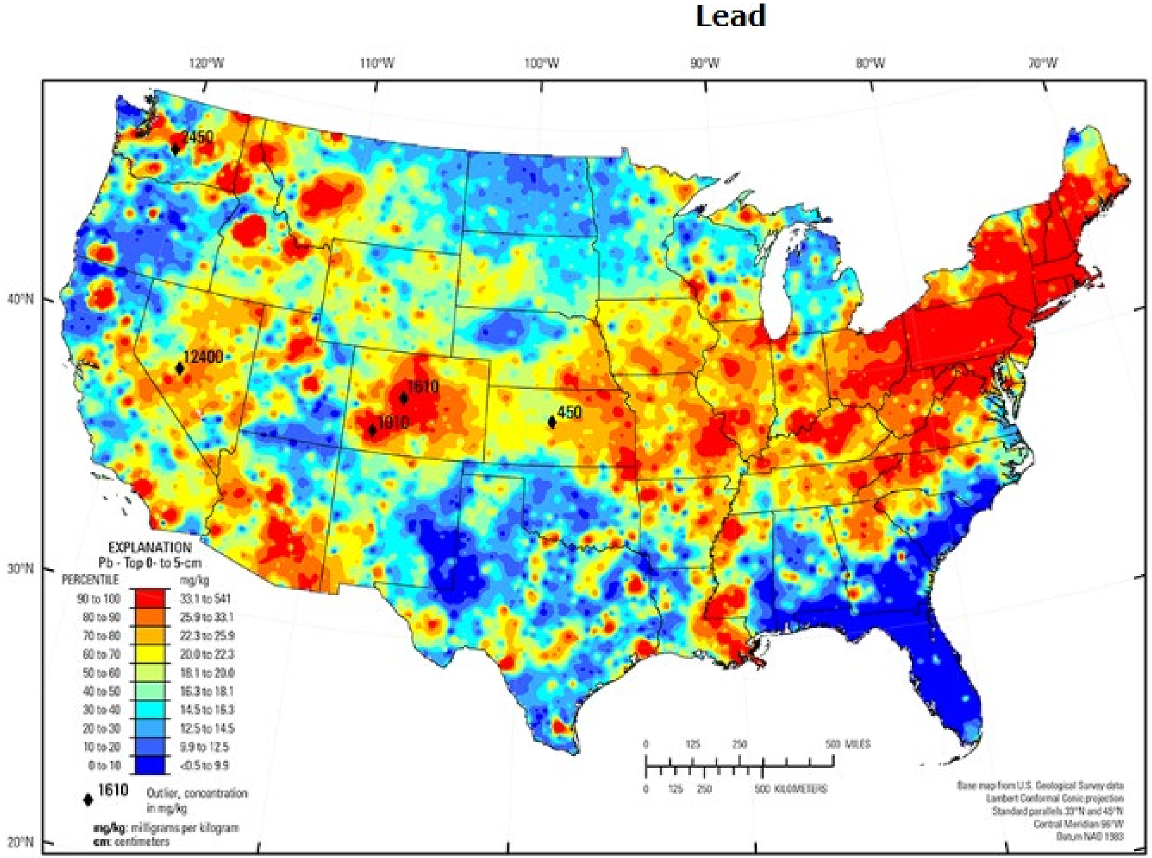


Common Anthropogenic Sources of Contaminants of Emerging Concern (CEC)[1]

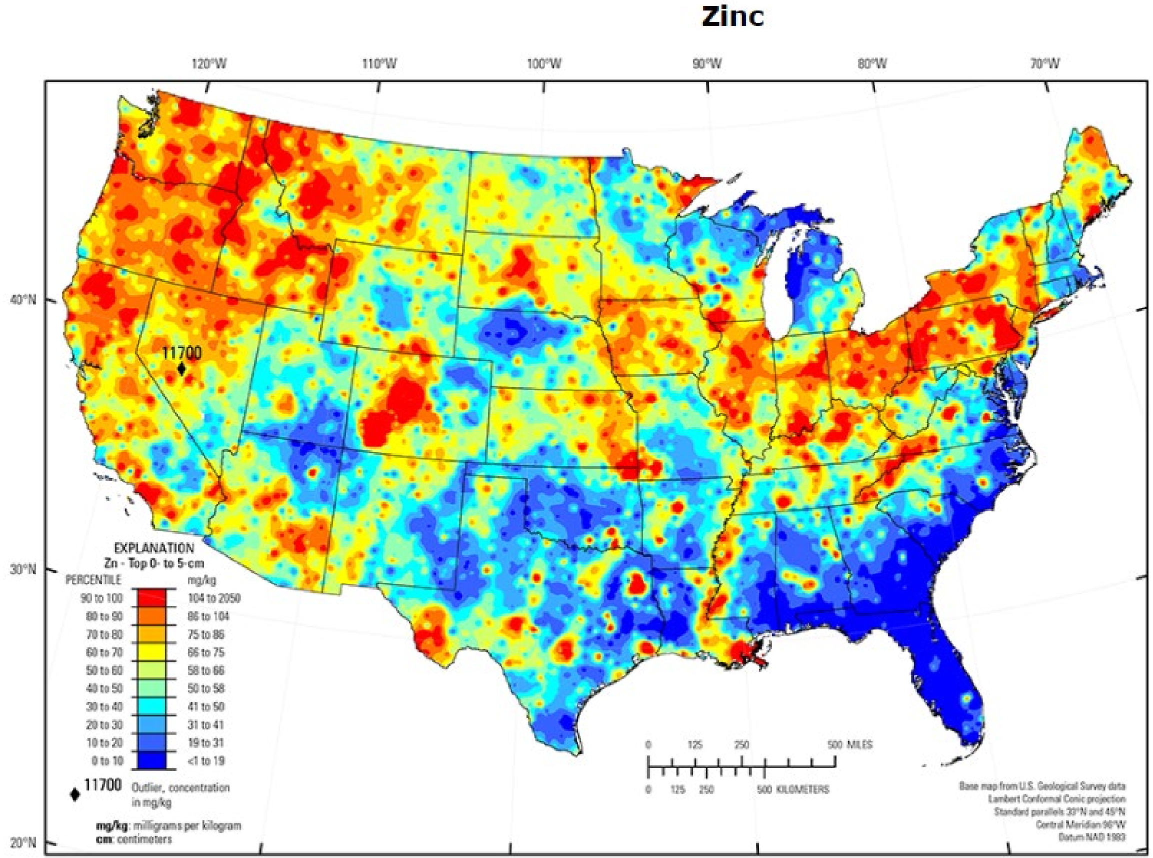
Source	Contaminant Type	
	Trace Elements	*Persistent Organic Pollutants (POPS)*
Paint (before 1978)	Pb	
High traffic areas	Pb, Zn	PAHs
Treated lumber	As, Cr, Cu	
Burning wastes		PAHs, Dioxins
Contaminated manure	Cu, Zn	
Coal production	Mo, S, Se	PAHs, Dioxins
Sewage sludge	Cd, Cu, Zn, Pb	
Petroleum refining/spills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

Lead (Pb); Zinc (Zn); Arsenic (As); Chromium (Cr); Copper (Cu); Molybdenum (Mo); Sulfur (S); Selenium (Se); Cadmium (Cd); Mercury (Hg); Barium (Ba); Organochlorine (OC); Polybrominated diphenyl ethers (PBDEs); Polychlorinated biphenyls (PCBs); Per- and polyfluoroalkyl substances (PFAS)

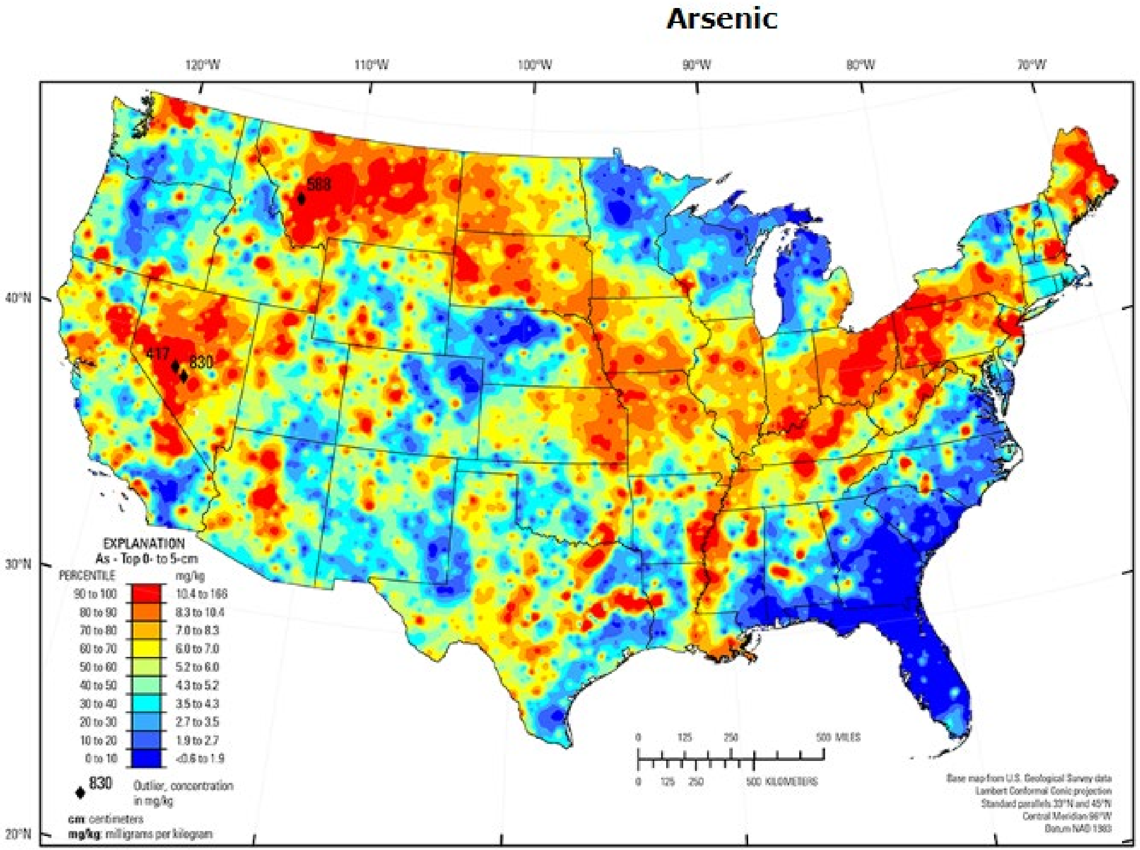
State Specific CECs: Lead[2]



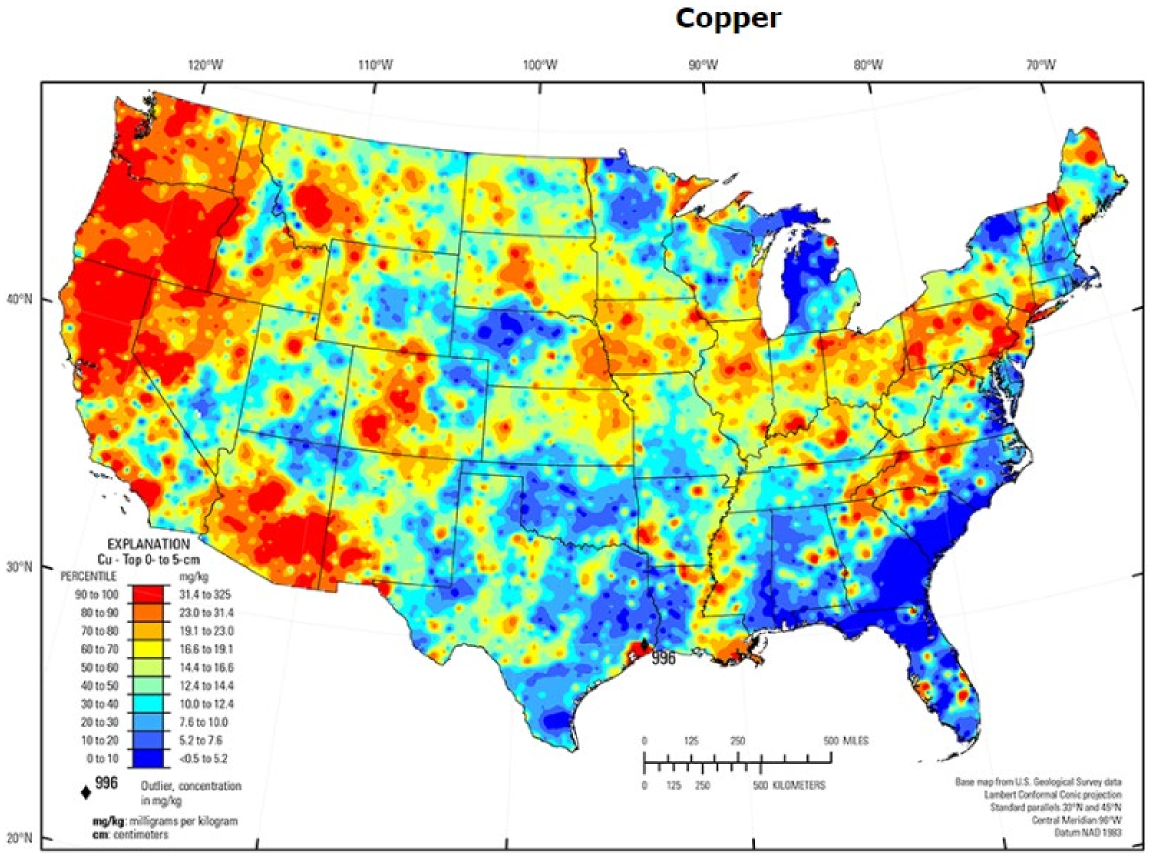
State Specific CECs: Zinc[2]



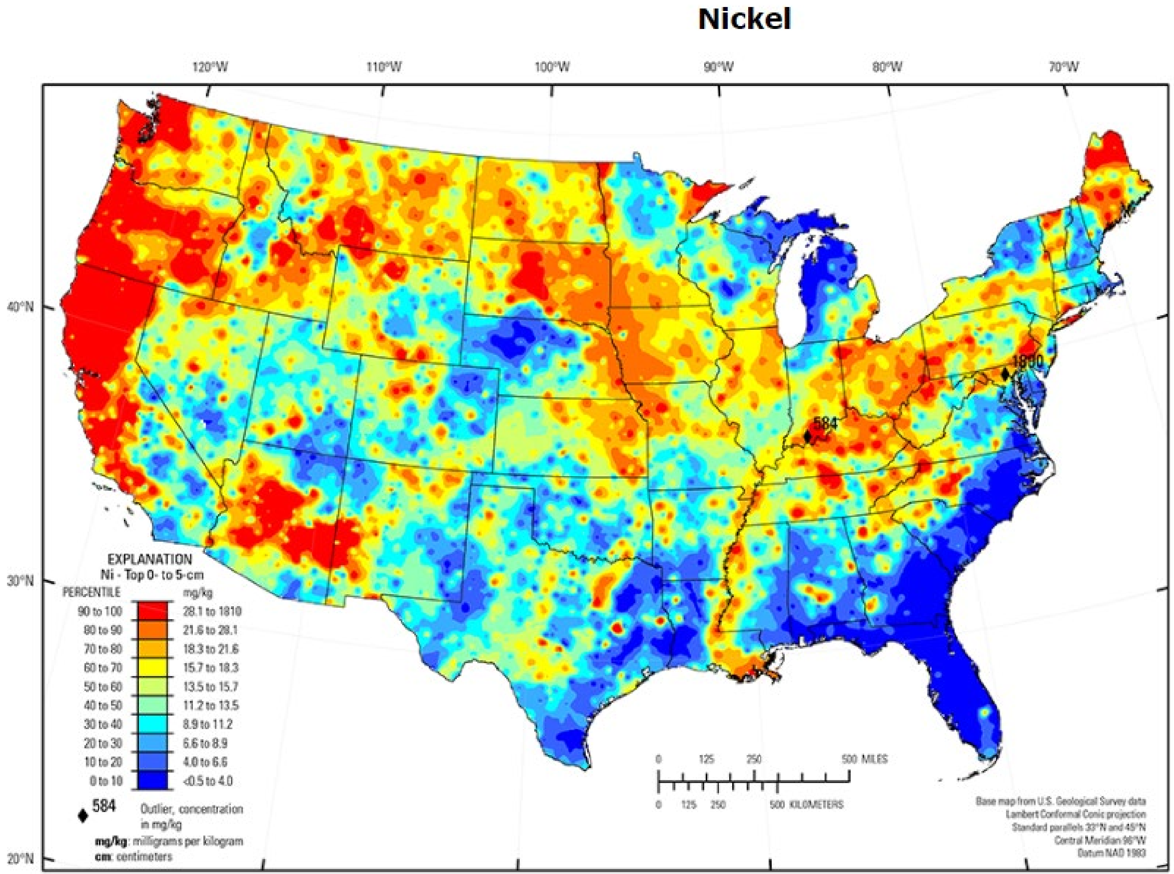
State Specific CECs: Arsenic[2]



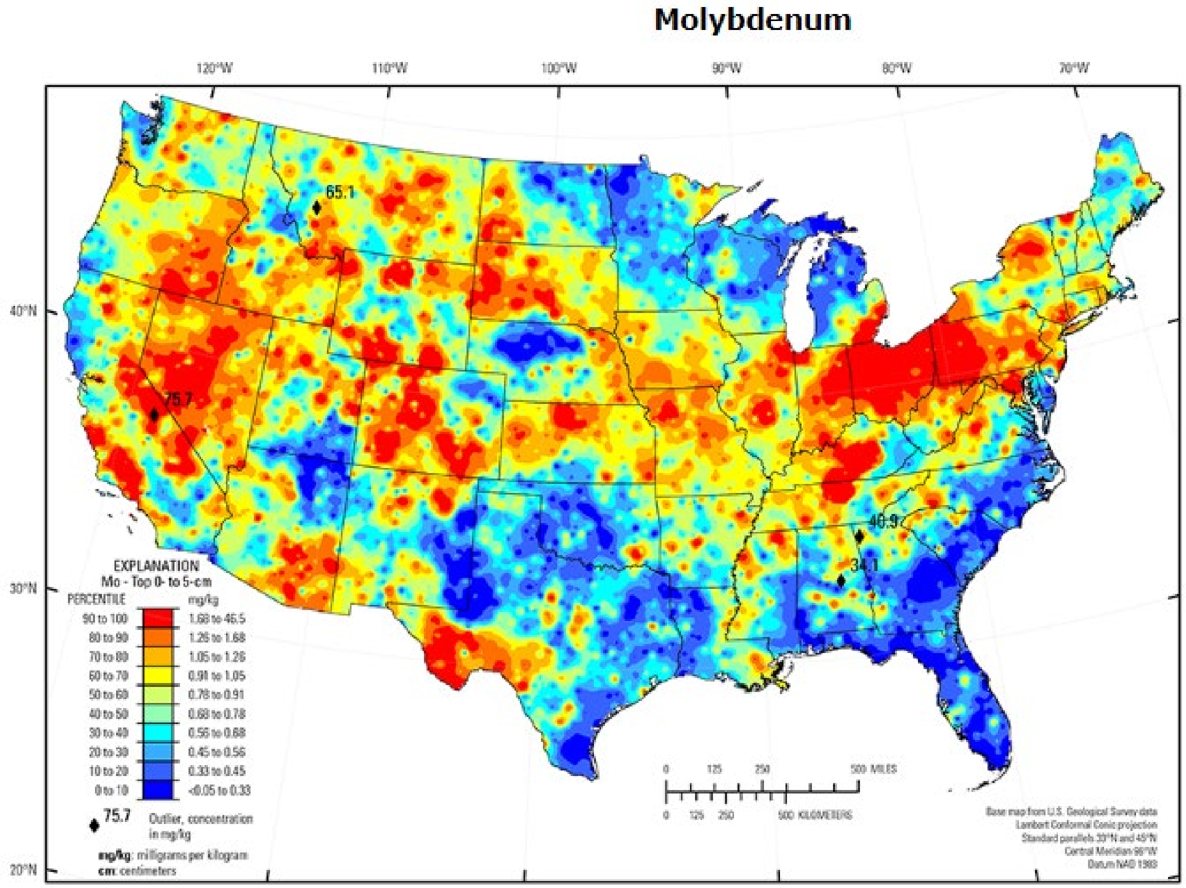
State Specific CECs: Copper[2]



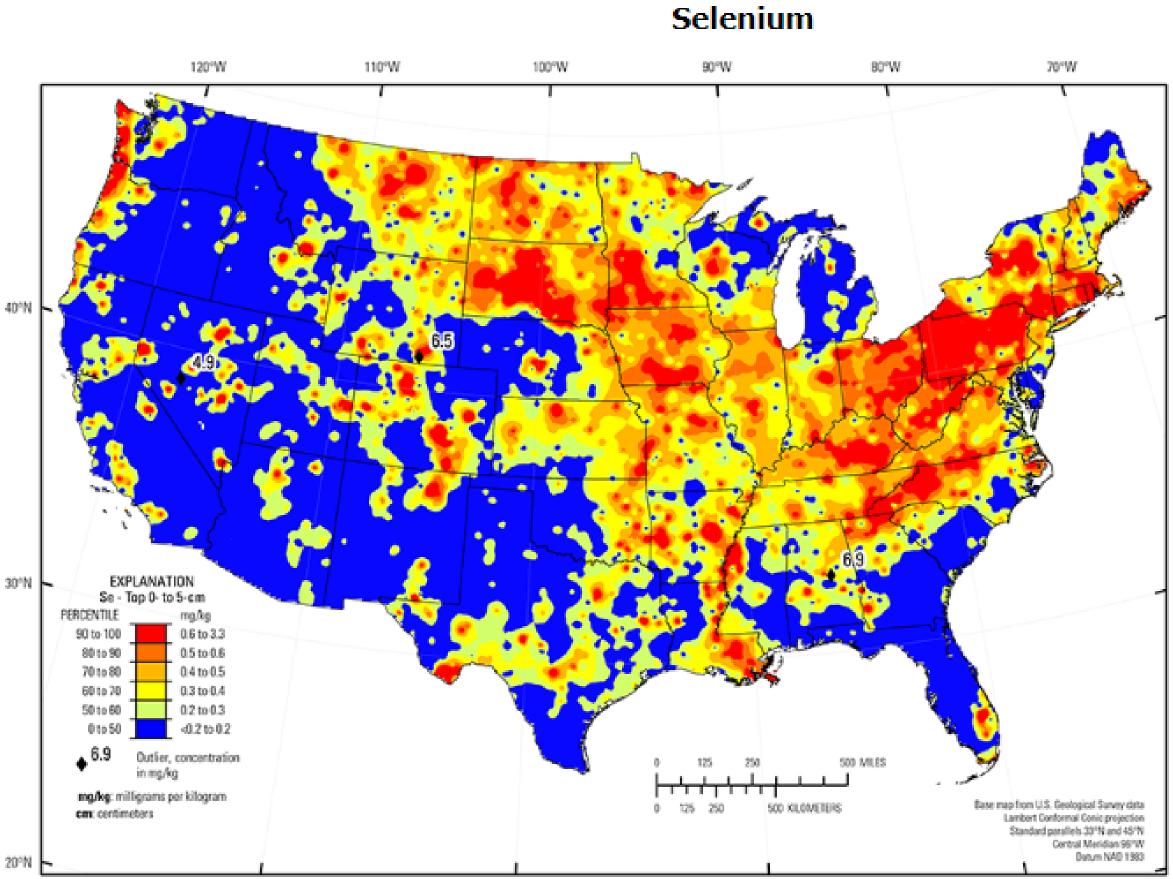
State Specific CECs: Nickel[2]



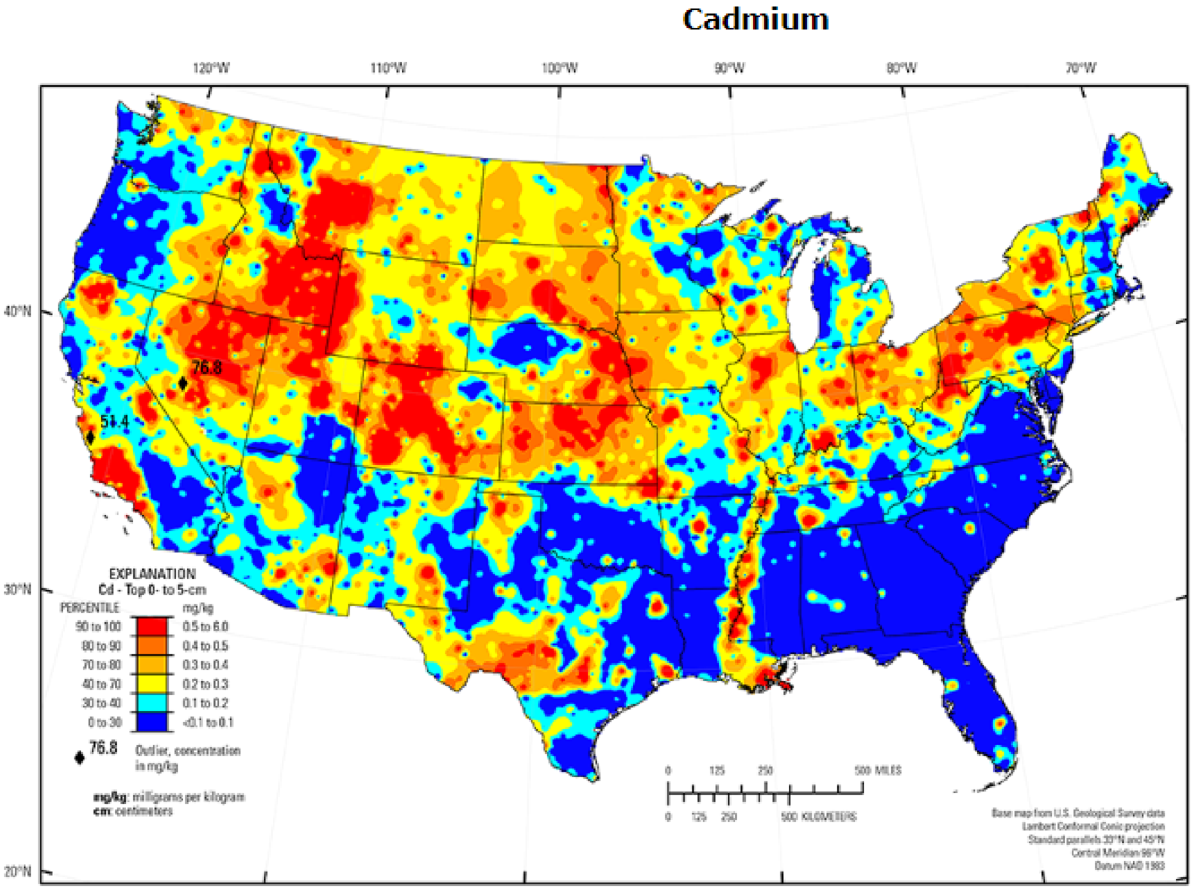
State Specific CECs: Molybdenum[2]



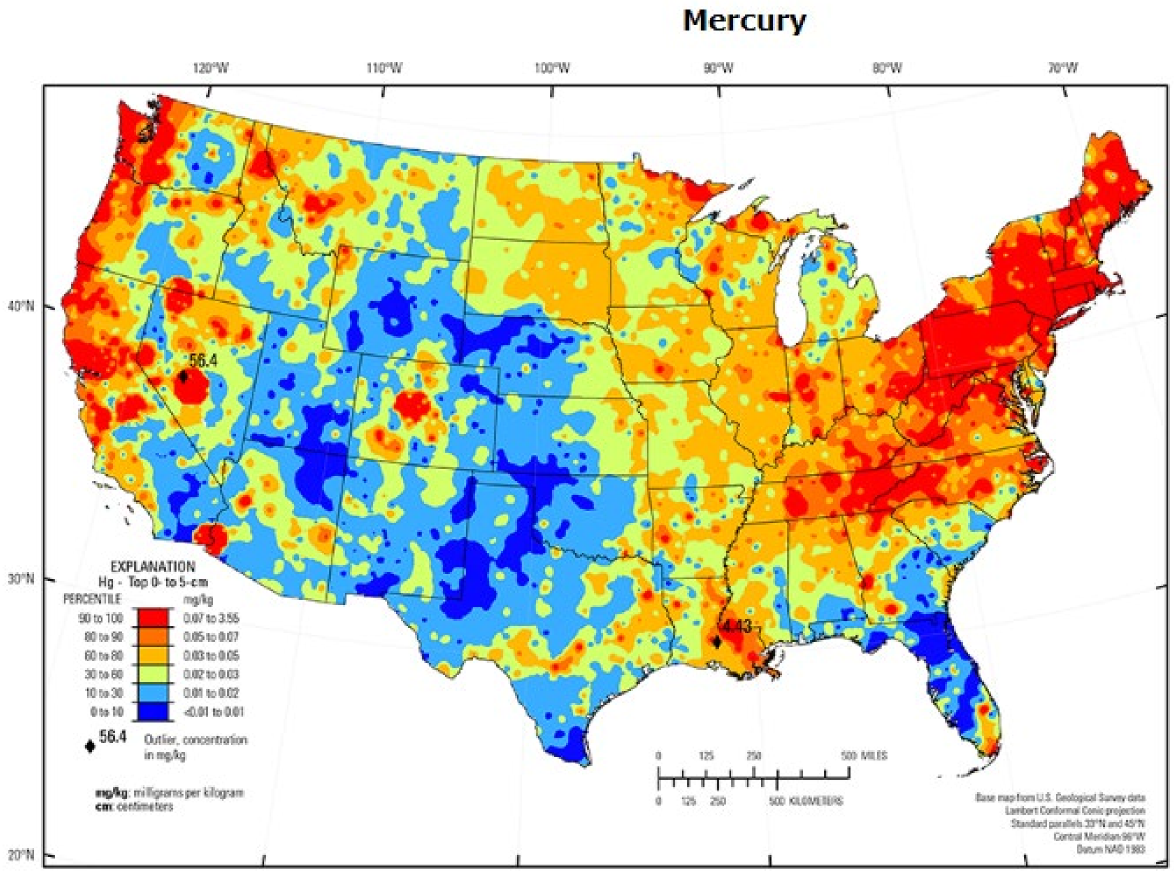
State Specific CECs: Selenium[2]



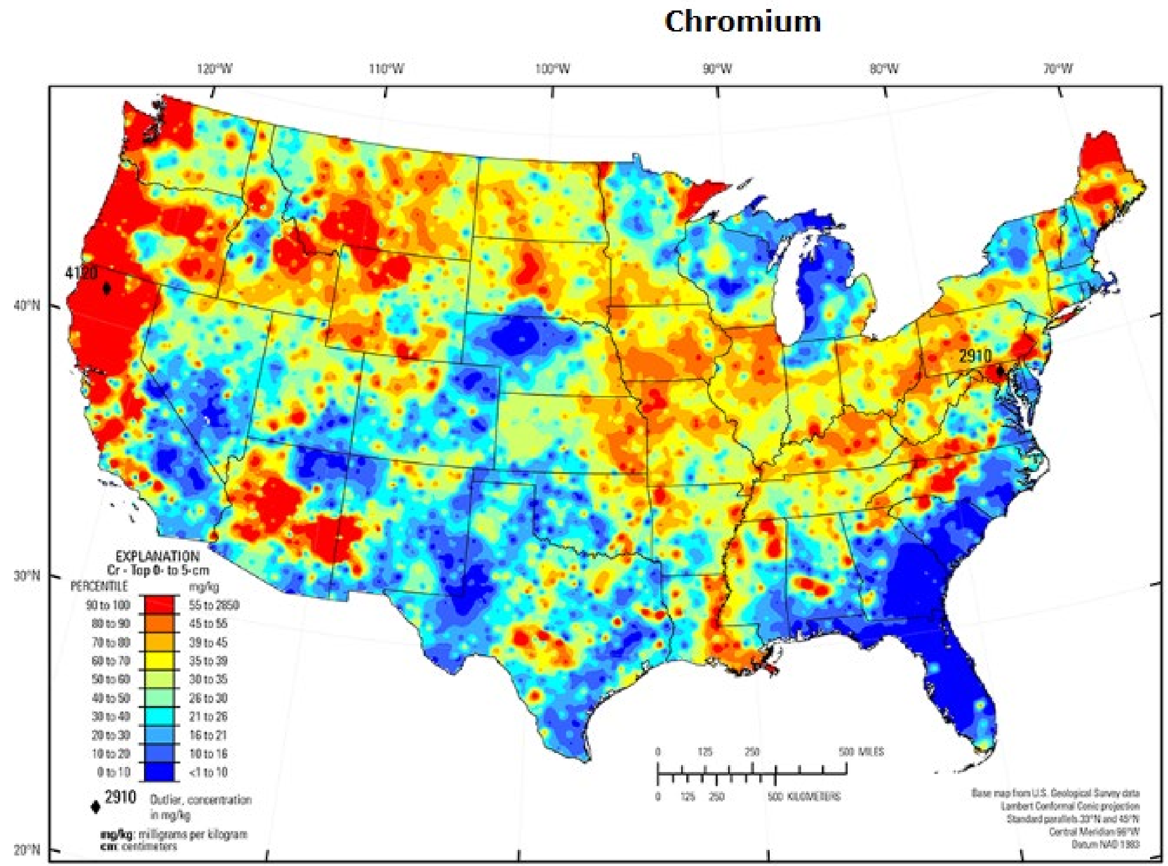
State Specific CECs: Cadmium[2]



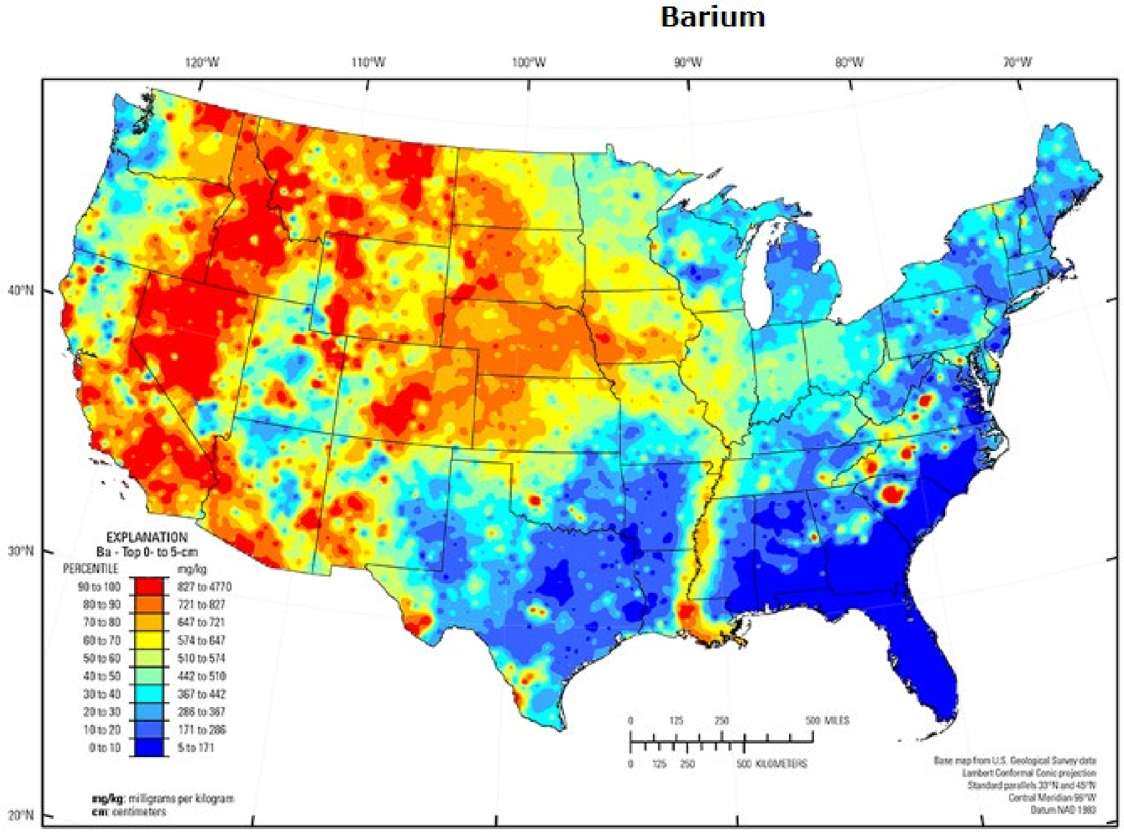
State Specific CECs: Mercury[2]



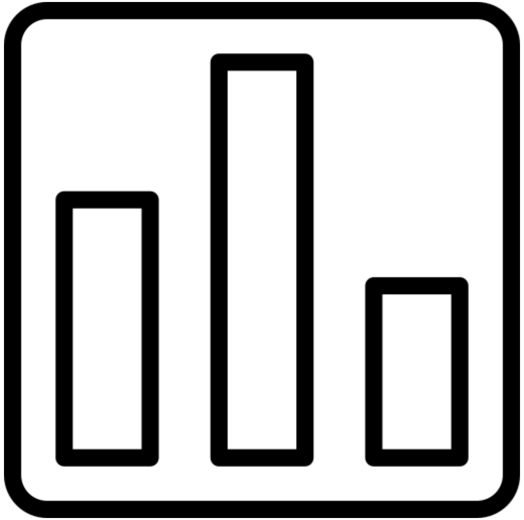
State Specific CECs: Chromium[2]



State Specific CECs: Barium[2]

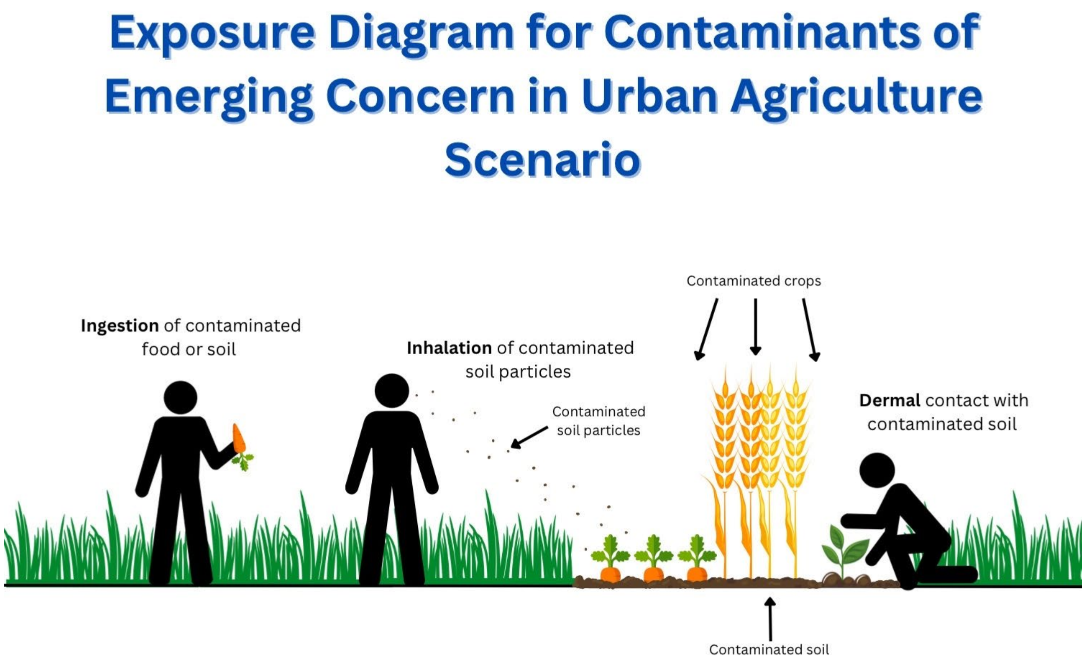


Poll Time!



Risk Assessment for Potential Exposure to CECs in Urban Agriculture[3]

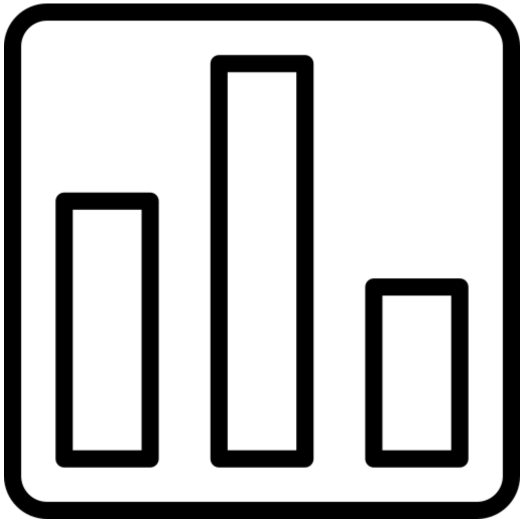
- Exposure routes to CECs in urban soils:
  - Ingestion
  - Inhalation
  - Dermal



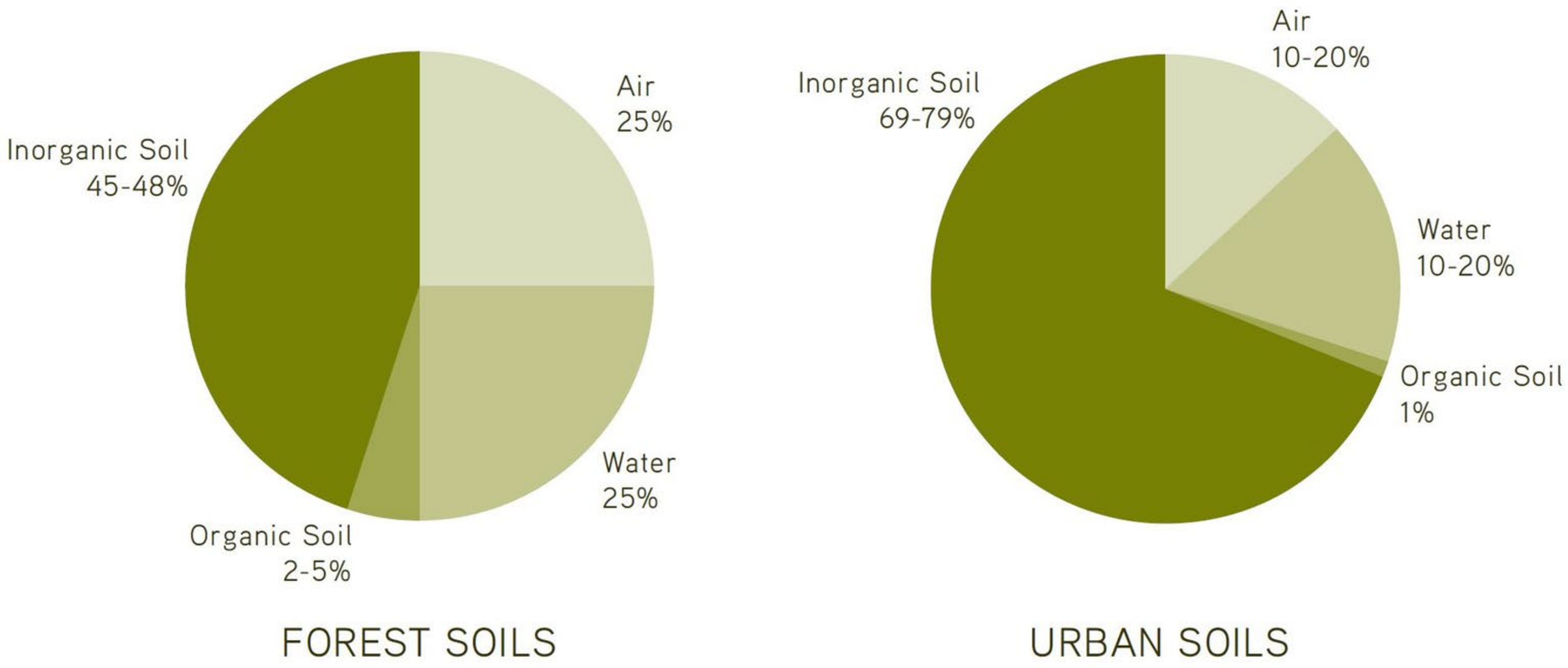
Risk Assessment for Potential Exposure to CECs in Urban Agriculture[3]

Organ/System	Observed Effects
Cardiovascular	Heart attack, heart failure, rapid heart rate
Dermal	Contact dermatitis, skin ulcers, skin discoloration, warts, hair loss, tooth decay, nail loss, lesions, chloracne, hyperpigmentation
Developmental	Decreased IQ, cognitive delays, delayed growth,
Endocrine	Endocrine system disruption
Gastrointestinal	Nausea, abdominal pain, vomiting, diarrhea
Hematologic	Anemia, copper deficiency
Hepatic	Liver damage, liver dysfunction, liver failure, liver cancer
Immune	Fever, decreased white blood cell count
Musculoskeletal	Joint pain, muscle aches, decreased bone strength, muscle weakness
Nervous	Mood disorders, confusion, headaches, fatigue, dizziness, paralysis, cognitive dysfunction, memory loss, tremors, decreased mental alertness, unconsciousness, drowsiness, hearing loss, lightheadedness, impulsivity, spasms, convulsions, seizures, acute encephalopathy, decreased attention span, behavioral abnormalities
Ocular	Vision loss, color vision loss
Reproductive	Sperm abnormalities, miscarriage, infertility
Urinary	Kidney failure, kidney disease, elevated uric acid levels
Respiratory	Cough, shortness of breath/difficulty breathing, bronchitis, lung cancer, asthma attacks, acute respiratory distress, throat irritation, nasal irritation
Other	Decreased bodyweight

Poll Time!



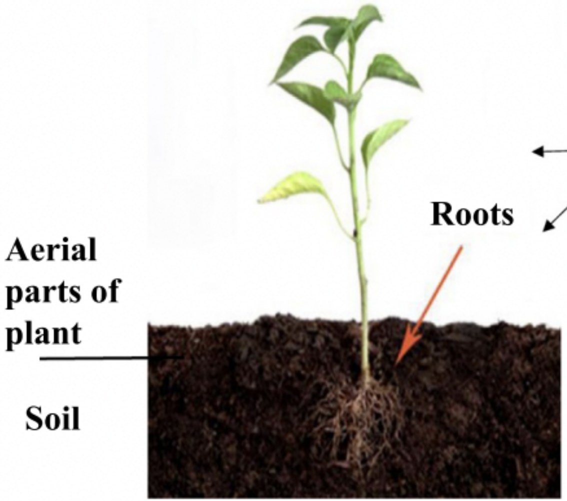
Urban vs Rural Soil Systems



Potential for uptake by and accumulation of CECs within the edible parts of crop plants[4]

Environmental factors affecting the potential for CECs' uptake by plants

	+		-
factors affecting evapotranspiration	high temperature	↔	low temperature
	high wind speed	↔	calm wind - low wind speed
	low air humudity	↔	high air humitidy
	hot and dry agricultural areas	↔	cold continental agricultural areas
	adequate soil moisture	↔	drought



Plant physiology parameters affecting the potential for CECs' uptake by plants

	+		-
factors affecting plants evaporation rate	plant genotype (genus and species)-leafy vegetables	↔	crops with small root ststem/succulent plants
	growing season during summer		growing season during the rainy period
	healthy plants (non-stressed plants)	↔	stressed plants
	high plant evapotranspiration (high Kc values)	↔	low plant evapotranspiration (low Kc values)
	high net irrigation requirements	↔	low net irrigation reguirements
	low lipid content in roots	↔	high lipid content in roots

Soil properties affecting the potential for CECs' uptake by plants

+		-
low levels of SOM	↔	high levels of SOM
sandy soils	↔	clay soils
sandy soils	↔	loamy soils
acidic pH (pH<pKa of CEC)	↔	basic pH (pH> pKa of CEC)
aerated soils (aerobic conditions)	↔	waterlogged soils (anaerobic conditions)

Potential for uptake by and accumulation of CECs within the edible parts of crop plants[4]

Physiochemical Properties of Pollutants

+	-
Low molecular weight (MW)	High molecular weight (MW)
Hydrophilic	Hydrophobic

Transpiration stream concentration factor (TSCF): the ratio of chemical concentration in the transpiration stream to to the concentration found in the external solution.

Contaminant uptake and translocation by plants[5]

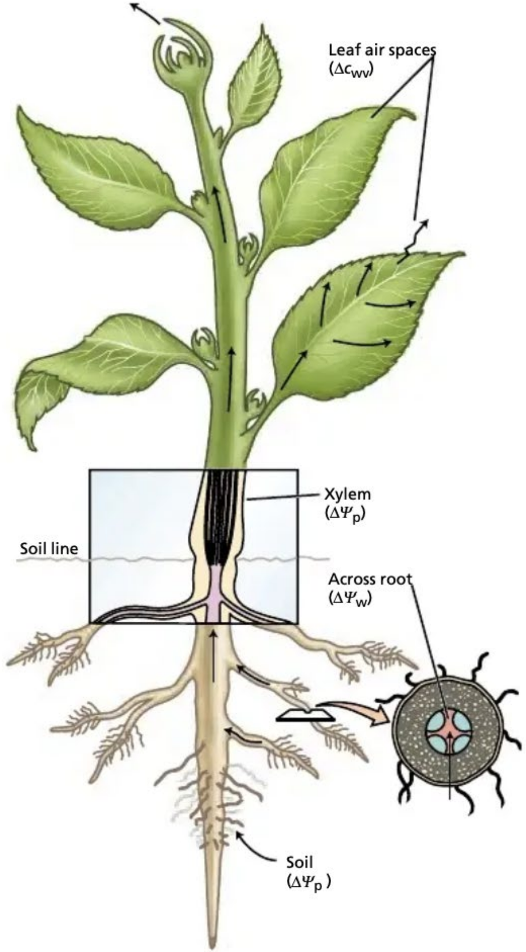
Contaminant uptake by plants generally follow two main uptake pathways:

(i) Extracellular transport

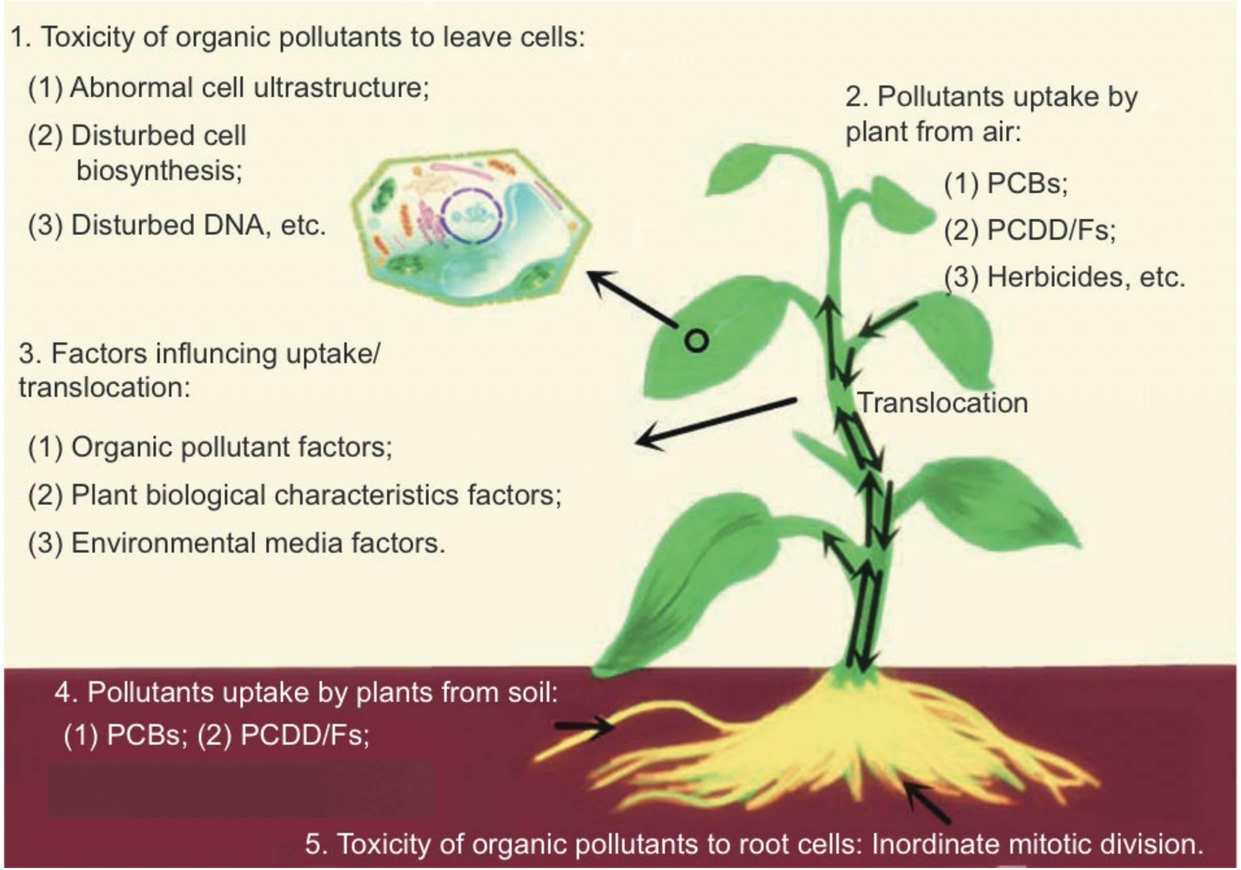
- Depends on nature of elements only
- Physiological conditions have no effect on uptake rate

(ii) Intracellular transport

- Depends on:
  - Pollutant factors
  - Plant biological characteristics
  - Environmental media factors



Contaminant uptake and translocation by plants[5]



Quantifying Uptake of CECs Across Plant Species[5]

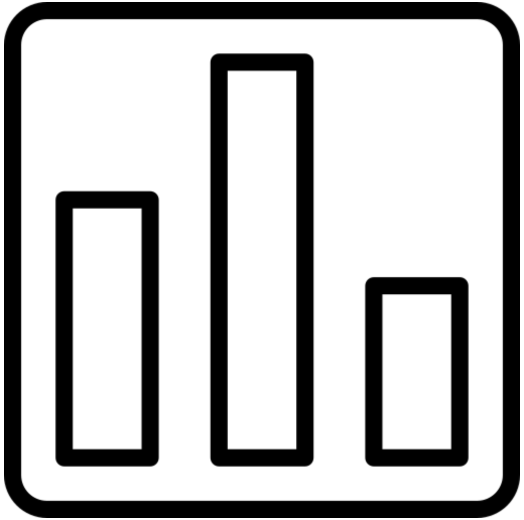
- Fruit vegetables growing under control greenhouse conditions (i.e. cucumber, green beans, tomatoes) have higher potential to uptake and accumulate CECs in their edible parts compared to plants cultivated in open fields.
    - Due to:
        - longer growing and irrigation period
        - higher net irrigation requirements (NIR) values
        - water requirements met solely with irrigation–no precipitation events occur in protected agriculture.
- Fruit vegetable crops uptake and accumulate CECs based on their reported bioconcentration factor (BCF) and net irrigation requirements (NIR) values

cucumber > okra > tomatoes > green beans > eggplants > pepper > melons > marrows > watermelons > artichokes > peas

Quantifying Uptake of CECs Across Plant Species[5]

Highest potential for CEC uptake by plants	Celery, spinach, lettuce, cabbage, carrots, radish, late-season potatoes, spring potatoes, mid-season potatoes, cucumber, green beans, okra, marrows, tomatoes, watermelons, melons
Lowest potential for CEC uptake by plants	pepper, eggplant, maize, alfalfa, peanuts, haricot beans, wheat, barley, bananas, walnut, citrus, avocado, fruit trees, pistachio, table olives, almonds, table grapes

Poll Time!



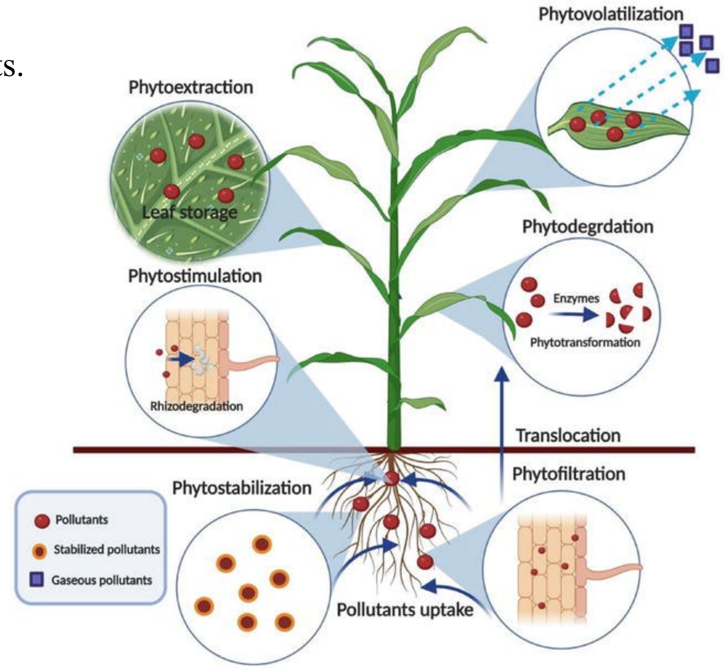
Remediation of Contaminated Urban Soil[6]

- Remediation methods:
  - Bioremediation- Cost-effective, minimally invasive, beginner-friendly
    - Phytoremediation
    - Mycoremediation

  - Other Methods- More expensive, more invasive, requires expert knowledge
    - Soil washing
    - Thermal treatment
    - Electrokinetics

Remediation of Contaminated Urban Soil[7-18]

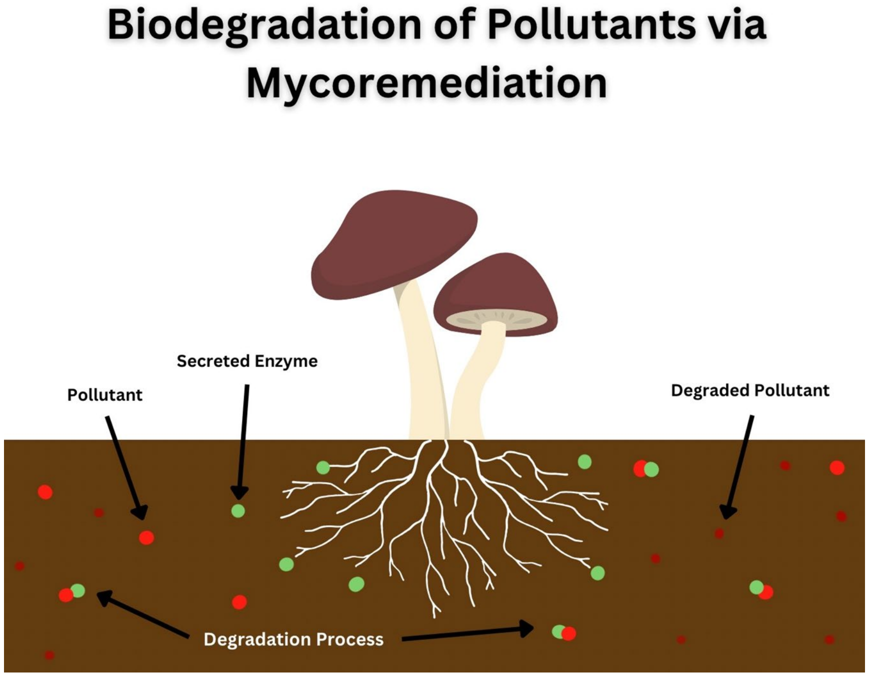
- Phytoremediation
  - Utilizes natural plant processes to remove or degrade soil pollutants.
  - Phytoextraction, phytodegradation, & phytostabilization are most applicable techniques in urban soil
- Studies on phytoremediation of CECs:
  - Trace elements
  - Dioxins
  - OCPs
  - PCBs
  - PFAS
- Limitations:
  - Time- Phytoremediation can take years.
  - Severity- Contamination must be low-moderate otherwise plants will not survive.



(Krishnasamy et al. 2022)

Remediation of Contaminated Urban Soil[19-25]

- Mycoremediation
  - Utilizes fungi to remove or degrade soil pollutants.
- Studies on mycoremediation of CECs
  - Petroleum products
  - Dioxins
  - Trace elements
  - PFAS
- Limitations:
  - Lack of research- Mycoremediation is a fairly new concept and requires more research studies to determine effectiveness.



Best Practices[26]

- Research the area in which you will be gardening before you start
- Get your soil tested
- Research pesticides and fertilizers that you will be using for any concerning chemicals
- Research what plants absorb CECs more than others
- Use soil amendment to stabilize contaminants in your soil
- Remove all contaminated soil and replace it with clean soil
- Use bioremediation techniques (i.e. phytoremediation, mycoremediation)
- When in doubt, grow your plants in pots or other means of above ground planting

Soil Testing[27-29]

- **Trace Elements**
  - Commercially sold kits are available for purchase online to test your soil for certain contaminants at home
    - Does not have a wide range of contaminants they can test for
  - Soil samples can also be sent to state universities that have an agricultural program that offers soil testing to the public or privately owned labs that conduct soil testing.
    - Methods Used: ICP-MS and ICP-OES

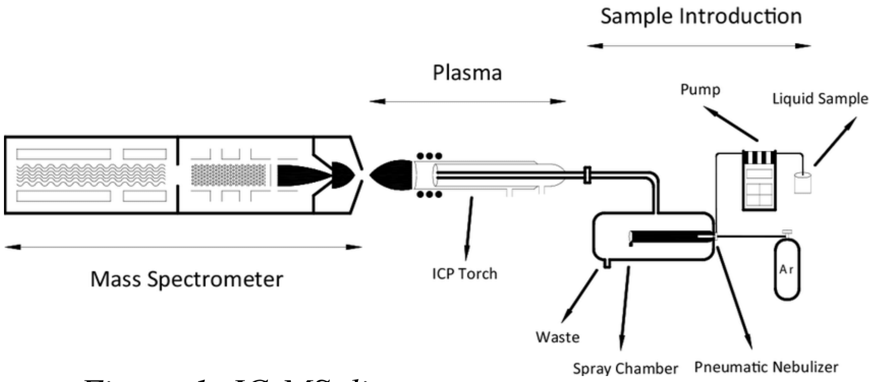


Figure 1: IC-MS diagram

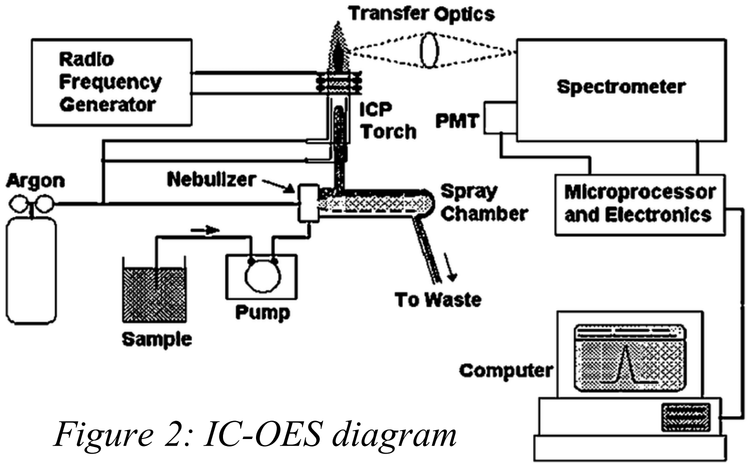


Figure 2: IC-OES diagram

Soil Testing[27-29]

- **Persistent Organic Pollutants**
  - Testing for persistent organic pollutants can be done by sending soil samples to specific labs that have the ability to test for these kinds of pollutants. This can be done through a few different methods:
    - Methods Used: GC-MS, LC-MS, HPLC, IC-MS

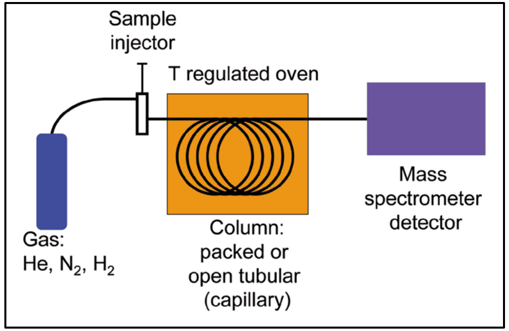


Figure 1: GC-MS diagram

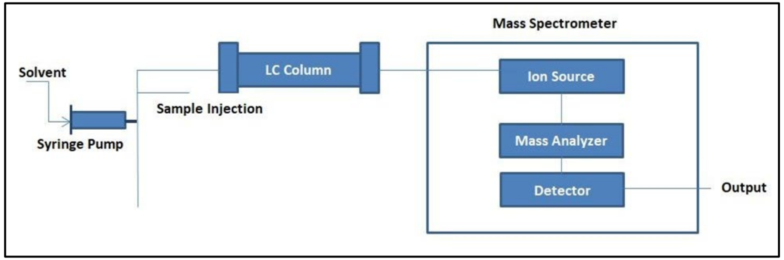


Figure 2: LC-MS diagram

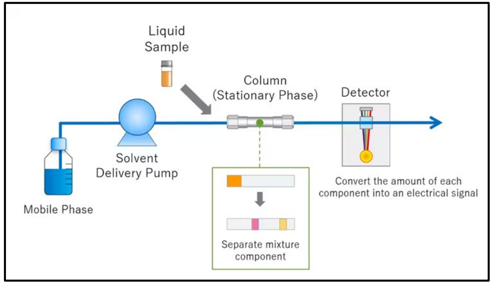


Figure 3: HPLC diagram

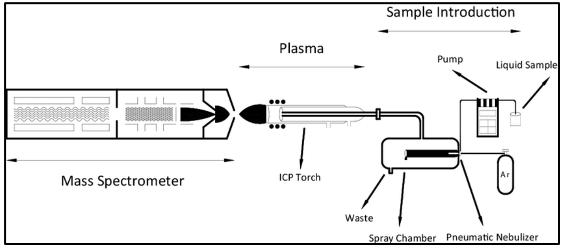


Figure 4: IC-MS diagram

Regional Trends of Common Crops Grown in Urban Areas

- **Region 1**: Maine, New Hampshire, Massachusetts, Vermont, Rhode Island,Connecticut
- **Region 2**: New York, New Jersey
- **Region 3**: Pennsylvania, Delaware, Maryland, Virginia, West Virginia
- **Region 4**: Kentucky, Tennessee, North Carolina, South Carolina, Mississippi, Alabama, Georgia, Florida
- **Region 5**: Ohio, Michigan, Indiana, Illinois, Wisconsin, Minnesota
- **Region 6**: Louisiana, Arkansas, Oklahoma, Texas, New Mexico
- **Region 7**: Nebraska, Kansas, Missouri, Iowa
- **Region 8**: Montana, North Dakota, South Dakota, Wyoming, Utah, Colorado
- **Region 9**: Arizona, Nevada, California, Hawaii
- **Region 10**:Alaska, Washington, Oregon, Idaho

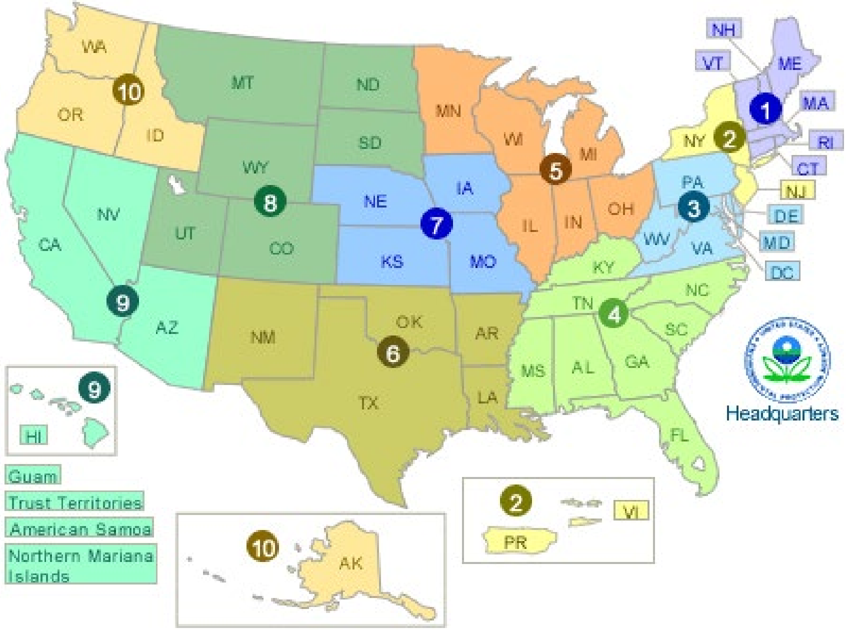
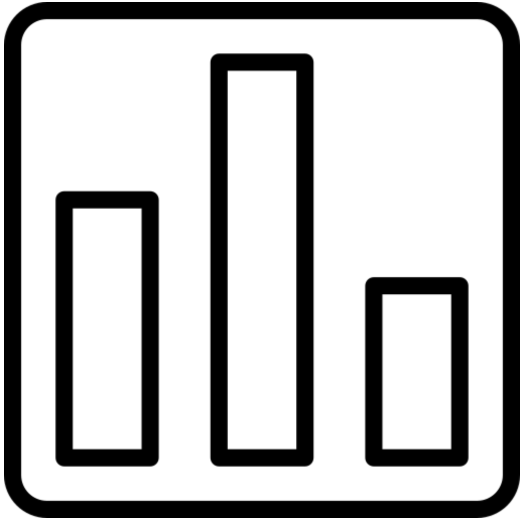


Figure 1: EPA Regions of the United States

Research Gaps

1. **Plant uptake models that can encompass all classes of contaminants**
2. How can we quantify the bioavailability of individual contaminants across plant species?
3. **State specific plant uptake models (what are individual states using?)**
4. What role do non-EPA agencies with authority to protect food supply, agricultural resources, and public health have in developing baseline standards for food production?
5. **A better scope on variability in plant uptake and exposure risk of CECs within plant species**

Poll Time!



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Please reach out with any questions and/or information that may help with phase 4 of this project!

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