Soils

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# Trace Element Contamination in Urban Soils: Testing and Management

*Melissa Chilinski, Melanie Stock, Paul Grossl, and Eli Oliver*

Trace elements, often referred to as heavy metals, naturally occur in the soil at low levels. Certain land use histories can elevate the concentrations of trace elements to levels that present health risks. Understanding which elements and soil test values may impact human or crop health is an important aspect of gardening and micro-farming, particularly in urban environments that are at increased risk of soil contamination. This fact sheet provides instructions on interpreting soil test results for trace elements through the **Total Element Composition EPA 3050B Soil Test** (#S19) at Utah State University Analytical Laboratory.

## Guidelines for Urban Soil Sampling

Screening urban soils for garden and farm suitability is important for human and crop health. The Utah State University Analytical Laboratory (USUAL) offers several test packages and pricing can be found here. To determine soil suitability for crop production and gardening, the **Basic Soil Test** (#S27) provides a general assessment of salinity, pH, and soil texture, while the comprehensive **Routine Soil Test** (#S28) includes salinity, pH, texture, phosphorus, and potassium. For soils at risk of trace element contamination, the **Total Element Composition EPA 3050B Digestion + ICP Analysis** (#S19) is recommended. For step-by-step instructions on how to collect a soil sample for testing, refer to pages 2-3 of Urban Garden Soils: Testing and Management. Depending on previous test results and risk factors, retest for trace elements every 5-10 years.

## Trace Elements and Bioavailability

USU's Total Element Composition Test provides the *total* soil concentration of trace elements, including heavy metals, metals, metalloids, and plant micronutrients. These naturally occur at low concentrations that do not negatively impact human or crop health. At elevated levels, usually due to prior land use, certain – but not all – trace elements can pose human and crop health risks.

***Figure 1.*** *An urban garden soil in Northern Utah.*

Trace elements persist in the soil for long periods of time because they do not readily degrade. Based on environmental conditions, such as soil pH, soil organic matter, weather, and land use, trace elements can become bioavailable. Though still difficult and slow, this means plants can more easily take up and accumulate trace elements, first in the roots, then in the stems and leaves, but generally not in fruits or seeds. Therefore, consuming root vegetables or leafy greens grown in contaminated soils can potentially increase human exposure to trace element contaminants. Consuming fruit (e.g. tomatoes, peppers, apples) or seed (e.g. corn, beans) crops pose the least risk and are considered safer. Bioavailable contaminants can also be toxic to plants (known as phytotoxicity) by inhibiting the plant's ability to absorb essential nutrients from the soil. This results in delayed or decreased germination, stunting, reduced yield, and other adverse effects.

Contaminant forms that are not bioavailable can also pose a risk to human health. Primary exposure occurs through direct contact with bare soils, such as through digging, planting, playing, or eating unwashed vegetables. Root crops present the greatest risk for exposure if not washed and/or peeled correctly.

## Common Contamination Sources

Low levels of trace elements naturally occur in the soil, but they can become elevated with previous land use histories and by location, particularly in urban environments. Testing soils for trace elements is highly recommended if common risk factors are identified on the property (Table 1), the property has an unknown history, and/or food crops will be grown.

## Screening Levels

The US EPA set **Regional Screening Levels** **(RSL)** to standardize human health exposure limits for trace elements. Relevant RSLs to urban farming and gardening are found under 'Resident Soil' and include an exposure limit in mg/kg (equivalent to units of ppm). As a result, some states have **State Guidance Levels (SGL)**. States may set their own levels because regional differences like soil composition (pH, texture, presence of other elements), climate, and land use affect the behavior of contaminants. Utah often refers to California SGLs because of the similar climate, soil, and farm practices.

## Total Element Composition Test Results

USUAL offers the **Total Element Composition EPA 3050B Digestion + ICP Analysis Soil Test** (#S19) that gives the *total* soil concentrations of 22 naturally occurring trace elements as % or mg/kg (EPA, 1996). An example of a soil test report is given in Figure 2. If there is not a result for an element, the value was below the lab's detection limit (i.e. the concentration was very low). Of the elements in the report, 10 of the 22 are particularly important, as they may be harmful to human health or inhibit crop growth at high concentrations. These include Arsenic (As), Cadmium (Cd), Chromium (Cr), Cobalt (Co), Copper (Cu), Lead (Pb), Manganese (Mn), Nickel (Ni), Selenium (Se), and Zinc (Zn), which are the focus of this fact sheet. The other 12 elements do not pose a risk at any levels, thus are not included in this fact sheet.

### *Arsenic (As)*

Arsenic is a common carcinogen and not a plant nutrient. It is often found at elevated levels in the soil. Long and short-term exposures to As can result in acute and chronic adverse health effects. Common sources of elevated As in soils include past use of lead arsenate pesticides, CCA pressure-treated lumber, mining, and coal ash. Suggested exposure limits vary from RSLs and SGLs. In Utah, precautions are recommended at soil test concentrations that are 12 mg $kg^{-1}$ and above.

### *Cadmium (Cd)*

Cadmium is a carcinogen and not a plant nutrient. It naturally occurs in soils from geological weathering and volcanic eruptions. Elevated soil levels of Cd are primarily caused by human practices like steel manufacturing, coal and incinerator emissions, and production of some phosphate fertilizers. Cadmium is more often in a

***Table 1***. *Land histories and features that can elevate risk of soil contaminants. Adapted from Stock et al. (2020)* Urban Garden Soils: Testing and Management.

| Property History or Feature | Reason for Potential Soil Contamination |
|---|---|
| Home built before 1978 | Soil surrounding the house could have elevated lead levels from lead-based paint chips, particularly older homes with siding. |
| Parked cars/vehicles | Leakage of oil, gasoline, or other chemicals. |
| Proximity to a highway | Trace element pollution from traffic road dust and roadside soils. Traffic density and vehicle speed increase risk. Contamination can occur up to 150 ft away from roads, but greatest risk is within 30 ft. |
| On an old orchard | Soil could have elevated lead and arsenic levels because lead arsenate was a common pesticide used from 1892 through the 1940s (banned in 1988). |
| Proximity to industrial facilities (refinery, smelter, construction site, mine, plant) | Soil could have elevated levels of contaminants from deposition, improper waste disposal, and/or previous mismanagement of leaks and spills. |
| Structures with pressure- treated wood built before 2004 | Until 2004, pressure-treated wood was preserved with Chromated Copper Arsenate (CCA) for residential use. |

bioavailable form and can accumulate in plant tissue, which accounts for the majority of total intake exposure (Amjad et al., 2017).

### *Chromium (Cr)*

Chromium can be a carcinogen and is not a plant nutrient. Elevated soil levels of Cr are primarily caused by CCA-treated lumber, steel and textile manufacturing, or paint and pigment spills. There are several forms of Cr; Cr (III) is the most common and Cr (VI) is most toxic, but quickly degrades into Cr (III). Generally, Cr (III) binds tightly to clays and organic matter across all pH levels, thereby reducing bioavailability, hence health risks. Chromium (VI) is carcinogenic and more mobile, although unlikely to be present unless a direct spill occurred that temporarily increased soil levels. *Note:* RSLs and the Total Element Composition Test results are for total Cr, reflecting that Cr (VI) quickly degrades into Cr (III), which accounts for much of total Cr.

### *Cobalt (Co)*

Cobalt is a potential carcinogen and is not a plant nutrient, although it may have a beneficial role in plant development at low levels (<15 to 25 mg $kg^{-1}$) (Hu et al., 2021). Elevated soil levels of Co are usually caused by mining, fertilizer production, or sewage waste. Risk of plant uptake increases with lower soil pH (soil acidity) and the form of Co present. Soil in Utah generally has a higher pH, which reduces human health risk from Co, however, it can be phytotoxic.

### *Copper (Cu)*

Copper is not a carcinogen, is a low risk to human health unless levels are excessive (>3,100 mg $kg^{-1}$), and is an essential plant micronutrient. Copper is widely used in organic pesticides and fungicides, as well as found in CCA-treated lumber, industrial waste, and municipal wastewater. Risk of plant uptake is very low, unless soil pH is less than 5.5, which is rare in Utah. Soil levels of Cu that are well below the human health threshold value for risk (e.g. 75 to 100 mg $kg^{-1}$) can be phytotoxic.

### *Lead (Pb)*

Lead is a common carcinogen that can be harmful to human health and is not a plant nutrient. It is especially hazardous to children and can cause permanent cognitive defects and high blood pressure and pregnancy challenges in adults. Elevated soil levels of Pb are usually caused by past use of lead paint, leaded gasoline deposition, and wind deposition of leaded dust or soil. Most risk of exposure comes from direct contact (e.g. digging, planting, playing, ingesting) with contaminated, bare soil. Lead is not bioavailable unless soil levels are high, organic matter content is low, and/or pH levels are <5.0 or >7.5. In these cases, Pb can bioaccumulate in plant tissue, particularly in leafy greens and root crops.

### *Manganese (Mn)*

Manganese is not a carcinogen and is an essential plant micronutrient. Elevated soil levels can be caused by industrial emissions, steel production, and combustion. Generally, Mn binds tightly to clays and organic matter at soil pH up to 8, making health risks less common in Utah unless soils are persistently waterlogged. Although Mn is an essential micronutrient, excessive concentrations in plant tissue can result in phytotoxicity, such as chlorosis and a reduced photosynthetic rate (Millaleo et al., 2010).

### *Nickel (Ni)*

Nickel is not a carcinogen, but poses moderate risk to human health at elevated levels (>1,500 mg $kg^{-1}$), and is an essential plant micronutrient. Elevated soil levels are usually caused by metal manufacturing, incinerator and fossil fuel emissions, and sewage sludge. Nickel bioavailability, hence health risk, increases at soil pH >7.5, which is common in Utah, but risk is low at pH 5.5 to 7.5. Soil levels of Ni that are well below the human health threshold value for risk (40-60 mg $kg^{-1}$) can be phytotoxic (Asajid and Ashraf, 2011).

### *Selenium (Se)*

Selenium is not a carcinogen or a plant nutrient, but elevated levels (>390 mg $kg^{-1}$) can pose short-term and long-term human health effects. Elevated soil levels are usually caused by industrial processes like glass, ceramics, and pharmaceutical production, as well as from coal deposition. At soil levels below the human health threshold value for risk (e.g. 100 mg $kg^{-1}$), Se can inhibit plant nutrient uptake and disrupt physiological and biochemical processes (Hasanuzzaman et al., 2020).

### *Zinc (Zn)*

Zinc is not a carcinogen and is an essential plant micronutrient. Elevated soil levels are usually caused by mine tailings, steel product manufacturing, wood preservatives, and industrial wastewater. Generally, Zn binds tightly to clays and organic matter at pH >6.0, making risk less common in Utah. Zinc levels that are well below the human health threshold value for risk (150-200 mg $kg^{-1}$) can be phytotoxic. Symptoms include stunting, leaf curling, and death of leaf tips (Rout and Das, 2003).

**Total Element Scan**

| USU ID | Identification | Al | As | B | Ba | Ca | Cd | Co | Cr | Cu |
|---|---|---|---|---|---|---|---|---|---|---|
| | | % | ---mg/kg--- | | | % | ---mg/kg--- | | | |
| 0252 | Grossl's Garden | 1.90 | 12.2 | 15.7 | 175 | 1.59 | 0.91 | 7.50 | 19.9 | 94.8 |
| Detection Limits: | | 0.00005 | 0.1 | 0.1 | 0.2 | 0.00001 | 0.1 | 0.1 | 0.1 | 0.1 |

| Fe | K | Mg | Mn | Mo | Na | Ni | P | Pb | S | Se | Sr | Zn |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| ---%--- | | | ---mg/kg--- | | % | mg/kg | % | mg/kg | % | ---mg/kg--- | | |
| 1.60 | 0.70 | 0.75 | 440 | 1.74 | 0.05 | 15.1 | 0.09 | 90.0 | 0.05 | 1.12 | 56.5 | 98.3 |
| 0.00001 | 0.0001 | 0.00001 | 0.1 | 0.1 | 0.00001 | 0.1 | 0.0001 | 0.1 | 0.0001 | 0.1 | 0.1 | 0.1 |

***Figure 2****. Example soil test results from USUAL's Total Element Composition EPA 3050B test that includes 22 metals and elements. The concentration of each element is given as % or mg/kg and laboratory detection limits are included below test results.*

## Analysis and Remediation Strategies

Guidelines for interpreting soil test values for the ten trace elements of potential concern are provided in Table 2, which lists the US EPA's RSL, SGLs for California, and suggested thresholds for management in Utah.

Test results within the Green Range are considered safe for farming and gardening – you are good to grow.

For results within the Yellow Range, be cautious and minimize exposure. Recommendations include building raised beds with uncontaminated topsoil and covering the surrounding native soil with mulch, turf, or rock to decrease airborne exposure and keep children from playing directly in the soil. For in-ground plantings, dilute the soil by tilling in low-salt sources of organic matter, such as plant-based compost, and uncontaminated topsoil. Avoid root vegetables and leafy greens, start a perennial garden, or grow inedible crops, such as cut flowers.

Stop growing and contact your local Department of Environmental Quality for remediation suggestions for soil results within the Red Range.

## Additional Resources


Agency for Toxic Substances and Disease Registry (ATSDR). 2012. Toxicological Profile for Manganese.

Amjad Khan, M., S. Khan, A. Khan, and M. Alam. 2017. Soil Contamination with Cadmium Consequences and Remediation Using Organic Amendments. Sci Total Environ, 601-2: 1591-605.

Asajid Aqueel Ahmad, M. and M. Ashraf. 2011. Essential Roles and Hazardous Effects of Nickel in Plants. Rev Environ Contam T, 214: 125-67.


***Table 2****. Regional Screening Levels (RSL) and State Guidance Levels (SGL) for ten trace elements in USUAL's Total Element Composition EPA 3050B soil test. Suggested thresholds for Utah indicate levels of increasing concern, with green, yellow, and red action plans.*

| | EPA | CA | Suggested Thresholds for Utah | | | |
|---|---|---|---|---|---|---|
| **Element Name** | **RSL** | **SGL** | **Low** | **Medium** | **High** | **Comments** |
| | ---------- mg/kg ---------- | | | | | |
| **Arsenic (As)** | 0.68 | 12 | <12 | 12-39 | ≥40 | Carcinogen |
| **Cadmium (Cd)** | 71 | 1.7 | <71 | | ≥71 | Carcinogen; crop risk |
| **Chromium (Cr)** | 120,000 | 100,000 | <100,000 | | ≥120,000 | Potential carcinogen |
| **Cobalt (Co)** | 23 | 660 | <23 | | ≥23 | Moderate human health risk; crop risk |
| **Copper (Cu)** | 3,100 | 3,000 | <3,100 | | ≥3,100 | Micronutrient; crop risk |
| **Lead (Pb)** | 400 | 80 | <80 | 80-399 | ≥400 | Carcinogen |
| **Manganese (Mn)** | 1,800 | N/A | <1800 | | ≥1800 | Micronutrient; crop risk |
| **Nickel (Ni)** | 1,500 | 1,600 | <1,500 | | ≥1,500 | Moderate human health risk; micronutrient; crop risk |
| **Selenium (Se)** | 390 | 380 | <390 | | ≥390 | Moderate human health risk; crop risk |
| **Zinc (Zn)** | 23,000 | 23,000 | <23,000 | | ≥23,000 | Micronutrient; crop risk |

Brown, S., R. Chanel, and G. Hettiarachchi. 2016. Lead in Urban Soils: A Real or Perceived Concern for Urban Agriculture? J Environ Qual, 45(1): 26-36.
California Environmental Protection Agency. 2005. Human-Exposure-Based Screening Numbers developed to Aid Estimation of Cleanup Costs for Contaminated Soil.
Centers for Disease Control and Prevention. 1992. Impact of Lead-Contaminated Soil on Public Health.
Chen, Q., T. DesMarais, and M. Costa. 2019. Metals and Mechanisms of Carcinogenesis. Annu Rev Pharmacol, 59: 537-54.
Delaware Health and Social Services Division of Public Health. 2013. FAQ: Arsenic Contaminated Soil.
Hasanuzzaman, M., M. Borhannuddin Bhuyan, A. Raza, B. Hawrylak-Nowak, R. Matraszek-Gawron, K. Nahar, M. Fujita. 2020. Selenium Toxicity in Plants and Environment: Biogeochemistry and Remediation Possibilities. Plants, 9(12): 1711.
Hu, X., X. Wei, J. Ling, J. Chen. 2021. Cobalt: An Essential Micronutrient for Plant Growth? Front Plant Sci, 12.
Kosiorek, M. and M. Wyszkowski. 2020. Remediation of Cobalt-Contaminated Soil Using Manure, Clay, Charcoal, Zeolite, Calcium Oxide, Main Crop (Hordeum vulgare L.) and After-Crop (Cynapis alba L.). Minerals, 10(5): 429.
Kovacik, J., D. Sterbova, P. Babula, P. Svec, and J. Hedbavny. 2014. Toxicity of Naturally-Contaminated Manganese Soil to Selected Crops. J Agr Food Chem, 62(26): 7287-96.
Krailertrattanachai, N. D. Ketrot, and W. Wisawapipat. 2019. The Distribution of Trace Metals in Roadside Agricultural Soils, Thailand. Int J of Environ Res Public Health, 16(5).
Kumar, V., S. Pandita, G. Singh Sidhu, A. Sharma, K. Khanna, P. Kaur, A. Shreeya Bali, and R. Setia. 2021. Copper Bioavailability, Uptake, Toxicity, and Tolerance in Plants: A Comprehensive Review. Chemosphere, 262.
Millaleo, R., Reyes-Diaz, M., Ivanov, A., Mora, M., Alberdi, M. 2010. Manganese as Essential and Toxic Element for Plants: Transport, Accumulation and Resistance Mechanisms. J Soil Sci Plant Nutr, 10 (4): 470-481.
Oliveira, H. 2012. Chromium as an Environmental Pollutant: Insights on Induced Plant Toxicity. J Bot, 2012.
Rout, G. and P. Das. 2003. Effect of Metal Toxicity on Plant Growth and Metabolism: I. Zinc. EDP Sci, 23(1): 3-11.
Stock, M. T. Maughan, and P. Grossl. 2020. Urban Garden Soils: Testing and Management. USU Extension Fact Sheet. Horticulture. Paper 2116.
Teaf, C., D. Covert, P. Teaf, E. Page, and M. Starks. 2010. Arsenic Cleanup Criteria for Soils in the US and Abroad: Comparing Guidelines and Understanding Inconsistencies. P Ann Int Conf Soils Sediments Water Energy, 15(10): 93-102.
Umair Hassan, M., M. Umer Chattha, I. Khan, M. Bilal Chattha, M. Aamer, M. Nawaz, A. Ali, M. Aman Ullah Khan, and T. Abbas Khan. 2019. Nickel Toxicity in Plants: Reasons, Toxic Effects, Tolerance Mechanisms, and Remediation Possibilities- A Review. Environ Sci Pollut R 26, 12673-88.
US EPA. 2021. Regional Screening Level (RSL) Summary Table.
Wisconsin Department of Health Services. 2010. Human Health Hazards: Lead Arsenate Pesticides in Soil.
Wuana, R. and F. Okieimen. 2011. Heavy Metals in Contaminated Soils: A Review of Sources, Chemistry, Risks, and Best Available Strategies for Remediation. Comm in Soil Sci and Plant Anal, 42: 111-122.
Yan, A., Wang, Y., Tan, S., Lokman Mohd Yusof, M., Ghosh, S., Chen, Z. 2020. Phytoremediation: A Promising Approach for Revegetation of Heavy Metal-Polluted Land. Front Plant Sci, 11(359).
Zaborowska, M., J. Kucharski, and J. Wyszkowska. 2016. Biological Activity of Soil Contaminated with Cobalt, Tin, and Molybdenum. Environ Monit Assess, 188(398).

## Acknowledgements

We sincerely thank Tiffany Evans, Manager of the Utah State University Analytical Laboratory, as well as the reviewers and editor for their feedback.

## Disclaimers

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