Urban Soils in Agriculture

Introduction

Interest in urban agriculture is increasing rapidly and, with that, the need for detailed soils information similar to or more detailed than that traditionally provided to the agricultural community. Most urban soils formed from different (i.e., human-affected) parent materials than natural soils and need different considerations for use and management. These considerations include the elevated levels of trace metals commonly found in these soils and the high spatial variability those metals commonly display. Soils in urban areas have a wide range of conditions and are known by many names, such as Anthrosols and Technosols (IUSS Working Group WRB, 2015), anthropogenic soils, and Urban land. Anthrosols are soils that formed in environments modified by human activities, such as additions of organic or mineral material, charcoal, or household wastes; irrigation; and cultivation. Technosols are soils that formed on significant amounts of artefacts, are sealed by technic hard material (such as pavement), or contain a geomembrane. Like natural soils, urban soils possess inherent and dynamic soil properties. The 12th edition of the Keys to Soil Taxonomy separates soils with human-altered or human-transported (HAHT) materials at least 50 cm thick. As defined in the Keys, human-altered material is the soil parent material that has been disturbed by human activity and human-transported material is soil parent material that has been moved from a different source by humans. These soils are recognized by one of seven specific subgroups (e.g., Anthrodensic). Their unique properties (properties that do not occur in more natural soils) are recognized by classes at the family level. For example, combustic (coal ash), artifactic (construction debris), and spolic (clean fill) are classes most common in the north-eastern part of the United States (Soil Survey Staff, 2014). In the urban environment, natural soils also commonly have additions of trace metals from the atmosphere. The combination of multiple land use and cover types, the variety of heterogeneous parent materials, and the effects of the urban environment result in a wide range of unique soil properties. This publication will discuss the possible use and management of urban soils. It will take into consideration the environmental concern for trace metals, such as copper, zinc, nickel, chromium, and cadmium, with a major focus on lead and arsenic. Although urban soils are spatially variable and, in some areas, polluted, they have potential for use in urban agriculture if they are assessed, managed, and used correctly, following best management practices (BMPs) or alternative farming practices.
Trace Metals and Urban Soils

Initial studies of urban soils focused on contamination and exposure to human health and largely ignored the spatial variation found in urban landscapes. Therefore, trace metal contamination was not considered in early attempts to map and classify urban soils (Lehmann and Stahr, 2007; Rossiter, 2007). The association of contamination and human health risks with trace metals in urban soils is not restricted to exposure by dust or ingestion (Clark et al., 2008; Hinwood et al., 2006) but also related to coarse fragments from construction debris or artifacts (Abel et al., 2015; Shaw et al., 2010). In addition, trace metals are not exclusive to highly disturbed urban soils in former industrial, waste disposal sites or parent materials such as construction debris, coal slag, fly ash, or mine spoils. Trace metals can occur in natural conditions from the parent material (Thomas and Lavkulich, 2015; Caillaud et al., 2009; Burt et al., 2000), but the concentrations are commonly less than in the soils formed on anthropogenic parent material. Largely unmodified soils in urban or peri-urban areas, such as parks and golf courses, can be characterized by an increase in trace metals in the surface layer. This increase can be traced to atmospheric deposition (Pouyat and McDonnell, 1991) or runoff-deposited inputs (Davis et al., 2001), especially for lead (Pb). Data collected in a peri-urban farm site located near a major State highway in New Jersey illustrate an example of atmospheric deposition (fig. 1). Data collected with a portable X-ray fluorescence instrument showed a higher concentration of lead in the soil surface layer compared with the rest of the soil profile. Another study conducted by Sabin et al. (2005) in Los Angeles found that 57 to 100 percent of the trace metals found in stormwater are from atmospheric deposition.

Lead, copper (Cu), zinc (Zn), nickel (Ni), chromium (Cr), and cadmium (Cd) are among the most studied trace metals in urban environments (Kargar et al., 2015; de la Cueva et al., 2014; Bretzel and Calderisi, 2006). Coal combustion, industrial processes, sewage sludge, lead paint, leaded gasoline, pesticides, fertilizers, and pressure-treated lumber are among the common sources of Cu, Zn, Ni, Cd, Pb, and As found in urban soils. According to Councell et al. (2004) and Hjortenkrans et al. (2006) (as cited in Yesilonis et al., 2008) an additional source of Cu and Zn can come from brakes and tire abrasion. Lead is the trace element that has received the greatest attention as a major environmental concern (Fu et al., 2004), mostly because of the risk to humans by oral ingestion and dermal contact, especially in the case of children (Luo et al., 2011; Madrid et al., 2008). Arsenic can be a concern in urban soils and should be included in any investigation. This trace metal has low mobility in the soil. It is less commonly assessed than the other trace metals and not always detected in the presence of Pb. Furthermore, As commonly responds to management in a manner opposite to Pb. As a result, locations where both Pb and As are present are more difficult to manage, as described in the section below.

Table 1 shows average concentrations within a depth of 50 cm, in mg/kg, of some of the most common trace metals from HAHT soils analyzed in the Kellogg Soil Survey Laboratory (KSSL) database. Also shown are the New York State Department of Environmental Conservation (NYSDEC) Soil Cleanup Objectives for Residential Land Use, which were developed to consider residential exposures, including gardening. In comparing the average concentrations, the soil material types in the HAHT family classes follow the order: combustic > artifactic > spolic for As, Cd, Cu, Pb, and Zn. Since coal
Figure 1. Lead concentration in a Nixon soil on a peri-urban farm in New Jersey.

contains detectable levels of every element in the periodic table (Finkelman, 1999), it is expected that As, Cd, Cu, Pb, and Zn will be found in the combustic material derived from coal. Spolic and depositional (atmospheric) materials showed greater concentrations of Cr than combustic and artifactic, except for those artifactic soil materials dominated by wood pressure treated with chro-
mated copper arsenate (Moghaddam and Mulligan, 2008; Lebow et al., 2000, 2004). Nevertheless, the concentrations of trace metals for all four parent materials are largely inherent rather than the result of pedogenic processes (Burt et al., 2014). However, it can be misleading to compare depositional material with combustic, artifactic, and spolic materials in this manner, because the higher concentrations in the depositional material commonly occur in thin horizons in the soil surface, whereas the data in table 1 shows average concentrations within the upper 50 cm. Despite this, the depositional material still showed the highest concentration of Cr.

### Management Practices to Address or Prevent High Concentrations of Trace Metals in Urban Soils

Trace metals in urban soils present challenges for urban agriculture and green infrastructure. Management practices are available that can reduce the negative effects of trace metals and provide some onsite treatment. One of the most important steps in establishing an urban farm or community garden is to investigate the land use history for the area of interest to help identify potential pollution issues. In their study assessing the needs of education on soil contamination, Harms et al. (2013) found that urban gardeners and farmers need and want information and guidance on best management practices, such as soil remediation, crop selection, and produce handling, related to urban soils.

One practice is the use of raingardens. Raingardens are designed to collect stormwater runoff and thus serve as a type of bioretention system (fig. 2). They function as a filtration system in which soil pH and organic matter can be modified to increase the sorption of trace metals from runoff and reduce their

### Table 1. Average trace metal concentrations within a depth of 50 cm of the soil surface, in mg/kg, according to HAHT material class from soils in KSSL database.

<table>
<thead>
<tr>
<th>Parent Material</th>
<th>As</th>
<th>Cd</th>
<th>Cr</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Min</td>
<td>Avg</td>
<td>Max</td>
</tr>
<tr>
<td>Artifactual (n=3)</td>
<td>7.96</td>
<td>9.16</td>
<td>11.62</td>
</tr>
<tr>
<td>Spolic (n=14)</td>
<td>5.52</td>
<td>7.06</td>
<td>7.34</td>
</tr>
<tr>
<td>Combustic (n=3)</td>
<td>8.21</td>
<td>13.24</td>
<td>15.36</td>
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<tr>
<td>Depositional (n=1)</td>
<td>1.52</td>
<td>4.22</td>
<td>6.77</td>
</tr>
<tr>
<td>NYSDEC Residential Soil Cleanup Objective</td>
<td>16</td>
<td>2.5</td>
<td>36</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Parent Material</th>
<th>Cu</th>
<th>Pb</th>
<th>Zn</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Min</td>
<td>Avg</td>
<td>Max</td>
</tr>
<tr>
<td>Artifactual (n=3)</td>
<td>60.77</td>
<td>81.50</td>
<td>103.34</td>
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<td>27.47</td>
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<td>89.16</td>
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<tr>
<td>Depositional (n=1)</td>
<td>14.55</td>
<td>19.43</td>
<td>24.55</td>
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<tr>
<td>NYSDEC Residential Soil Cleanup Objective</td>
<td>270</td>
<td>400</td>
<td>2,200</td>
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</table>
impact on ground water and the surrounding areas. Rainwater runoff from building roofs and other impervious surfaces can be a source of trace metals in urban soils. Lamprea and Ruban (2011) analyzed roof and street runoff water and found poor water quality due to high concentrations of Pb and Zn. Quek and Förster (1993) found in their study that Zn sheeting produced higher concentrations of trace metals from roof runoff, although some leaching of Zn and Cu from the zinc roof was responsible for the increase in concentration. Nevertheless, the particles from deposition can be washed easily from the smooth surface. Quek and Förster also found the least concentration of trace metals in a gravel flat roof due to high pH from dissolution of CaCO₃ and the filtering and sedimentation effects of the gravel.

Phytoremediation is a practice that uses plants with a high affinity for trace metals, also known as hyper-accumulators. The Department of Agronomy at Kansas State University, in cooperation with the NRCS Plant Materials Centers, developed a database to provide a list of plants with potential for phytoremediation. This database can be downloaded from the university’s website. In a review by Kidd et al. (2009), two kinds of phytoremediation are discussed: phytoextraction (removal of trace metals by plant uptake) and
phytostabilization (establishment of a tolerant plant cover that reduces the mobility of the trace metals in place). The implementation of phytoremediation practices depends on the concentrations and form of trace metals in the soil; plants may not be effective in taking up metals if the trace metals occur in very low concentrations or have low bioavailability. According with McGrath and Zhao (2003), the efficiency of phytoextraction depends on biomass production and trace metal concentrations. In the case of phytostabilization, Cunningham et al. (1995) mentioned that this technique is more efficient with the relative immobile form of the trace metal and with soil that has high content of clay and organic matter. Some of the challenges in using phytoremediation listed by Mahar et al. (2016) are: (1) the time requirement for remediation, (2) the low biomass and slow growing rate, (3) the biomass disposal issue, (4) susceptibility to pests and diseases, (5) limited bioavailability of trace metals, (6) the possibility of introducing invasive plants, (7) dependence on climate and weather, (8) plant growth in highly contaminated soil, and (9) requirement for soil fertilization and soil amendment that may reduce mobility of trace metals. In studying two bioaccumulators (Sorghum and Helianthus) as a way to remove trace metals, Marchiol et al. (2007) found that fertilization and application of soil amendments in the form of organic matter did not increase the concentrations of trace metals in the plant tissue. They concluded that organic matter might decrease metal availability by binding the elements. However, Wiszniewska et al. (2016) mentioned that plant uptake could be increased or decreased by inorganic or organic soil amendments.

Raised beds (fig. 3) are a commonly used and sometimes essential practice in urban soils where the trace metal concentrations reduce the potential to grow crops safely. Raised beds are boxes built from various materials that are free of harmful chemicals and filled with an uncontaminated growing media (natural soil, compost, or a mix of both) that provides support and nutrients to plants. The use of raised beds also eliminates soil compaction from foot traffic. The installation of a membrane or bottom barrier provides an extra precaution against plant root contact with trace metals in the soil or the upward movement of those metals by capillary action (US-EPA, 2011).

The addition of compost is highly recommended and, according to Brown et al. (2016), is one of the most common practices used by gardeners on urban soils. This practice provides an increase in organic matter, a source of slow-release nutrients, an increase in water-holding capacity, a clean growing medium, and a dilution of potential trace metals in the soil. The use of compost is supported in a study conducted by Ge et al. (2000), who found that high pH and/or organic matter content reduced the bioavailability by immobilizing the trace metals to the soil particle surface. Grimes et al. (1999) studied the availability and bonding of trace metals in compost and found that there is a strong bond between the trace metals and the compost, a bond that reduces the leaching of Pb, Cd, Cu, and Zn. Udovic and McBride (2012) found that the addition of compost to soil containing As and Pb decreased the bioavailability for Pb. However, the decrease in bioavailability for Pb is a response to an increase in pH and phosphorus concentration by the addition of compost, which increased mobility of As. In separate studies, Blanco et al. (2015) found the same response for Pb and As with the application of three different sources of phosphate. In addition, McBride et al. (2013) found that, with the application of mineral and organic amendments, As is transferred into the leafy greens by
root uptake more efficiently than Pb. Pb exposure is primarily through the soil particle transfer to the plant by the effect of raindrop impact on the soil surface.

Conclusion

Urban soils, when managed correctly, have great potential as a growing medium in urban and peri-urban areas and can provide fresh produce in zones identified as food deserts. Sources of increased concentrations of trace metals in urban soils include, but are not limited to, atmospheric deposition (such as dust), vehicular traffic, construction debris, industrial waste, and natural weathering of parent material (Silveira et al., 2016; Abel et al., 2015; Praveena et al., 2015; Iwegbue, 2014; Luo et al., 2012; Ona et al., 2006; Brinkmann, 1994). Raingarden and bioretention systems provide a medium with an optimum pH level and a high content of organic matter. They can concentrate runoff with potential trace metals from rooftop and impervious surfaces and divert it away from crops. In addition, they provide treatment of the water on site and thus reduce the overload of fluvial systems and the discharge of untreated water into rivers and streams. Phytoremediation is a method that utilizes adapted plants to either reduce the concentrations of available trace metals in the soil or to decrease the mobility of the trace metals and so reduce the potential of leaching. Phytoextraction uses plants to absorb the available trace metals into different part of the plants, which can be disposed or composted at the end of the growing season. Phytostabilization uses plant cover to absorb available trace metals, mostly into the root system with limited translocation to the rest of the plant, and decrease their mobility in the soil. Where urban soils are used for
Soil Quality – Urban Technical Note No. 4

agriculture, compost provides multiple benefits, including increasing organic matter content, slowly releasing nutrients, increasing water retention, improving soil structure, and acting as a bonding agent with trace metals to reduce their mobility. In areas not suitable for crop production and where the above practices are not viable, the use of raised beds is recommended. The main purpose of this practice is to provide a buffer zone between the soil material with a high content of trace metals and the crop root zone. Other recommended practices include soil screening for trace metals, replacing soil material with high concentrations of trace metals with clean topsoil, and protecting the soil surface with mulch or a cover crop. (Cover crops also provide other benefits, including a microenvironment for wildlife, pollinator habitat, and esthetic enjoyment for local residents.) Flisram et al. (2009) argued that urban farming is not a new concept, stating that what is new is the growing influence of urban agriculture in community and economic development.

Additional Resources

Soil Quality – Urban Technical Note No. 3: Heavy Metal Soil Contamination

State and Regional Soil Remediation Standards http://www.cleanuplevels.com/


References


