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Soil Health

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Basics of Urban Soil Health

Acknowledgments

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Cover Photo: An urban farm in Cleveland, Ohio. Photo by Joshua Beniston.

Table of Contents

Acknowledgments i
Introduction 1
Characteristics of Urban soil 2
Soil health resource concerns found in urban soils 4
Compaction 5
Concentration of salts and other chemicals 6
Organic matter depletion 7
Unsuitable material and soil sealing 7
Summary 8
Additional Resources 9
References 9

Introduction

Soil health is the continued capacity of soil to function as a vital living ecosystem that sustains plants, animals, and humans. Healthy soils plays a role in many different parts of the ecosystem, such as in the water cycle and as a habitat for a diversity of organisms. This remains true for urban areas where large numbers of people inhabit and interact with landscapes that are sustained by urban soils. In many cases, urban soils provide multiple ecosystems services simultaneously, including infiltration of stormwater, sustaining urban plant communities and gardens, and providing space for recreation (Pouyat et al. 2020). Urban soils also impacts the resilience of urban ecosystems to extreme weather events and climate change (Pouyat and Trammell 2019). However, landscapes in urban areas may largely be covered with impervious materials, meaning that urban soils are only able to provide these essential ecological services on a portion of the landscape. This makes the health and management of urban soils, as well as the societal awareness of these issues, particularly critical. The close proximity of people to soils in urban areas provides unique opportunities for education and interaction regarding urban soil health and management.

There is widespread interest in urban agriculture and gardening across the cities of the U.S. Urban agriculture takes many forms, most commonly backyard gardens, community gardens, and urban farms. Like urban soils, urban agriculture can provide many benefits to urban populations, such as growing food for the home, educating the community, and increasing the availability of fruits and vegetables in the surrounding area (Lal 2020). Many urban areas are considered food deserts, that is, areas where nutrient-rich foods are not readily available to the average citizen in the quantities needed for a healthy diet. In many U.S. cities, implementing urban agriculture on land that is currently underutilized could benefit community food security and even create economic opportunities (Colasanti and Hamm 2010). Healthy soils and management of soil health are key components for the success of urban agriculture.

USDA NRCS promotes four principles that guide the management of healthy soils: (1) maximize soil cover, (2) minimize (or optimize) soil disturbance, (3) maximize living roots, and (4) maximize biodiversity. These principles improve soil function by protecting the soil habitat and feeding soil organisms. The principles can be applied on different scales and across land uses and have strong potential for improving soil conditions at urban sites. Urban sites with a history of land use and management consistent with these principles (e.g., sites with minimal disturbance and continuous plant cover) are often associated with robust and healthy soil. The goal of this document is to promote understanding of soil health management at urban sites by summarizing information on urban soil properties and constraints or resource concerns.

Characteristics of Urban Soil

Urban soils vary in their composition and properties, existing on a continuum between those that are essentially native or natural soil types and those that have been highly altered by human activities. Population density, cultural and socioeconomic conditions, and the management history of individual sites are all factors that influence the composition and variability of urban soils. Site history and management in particular often play an overarching role in the conditions of urban soils. For example, sites that have had long-term vegetation, such as parks and urban forests, may exhibit high organic matter and well-developed soil structure. In contrast, sites with recent construction or demolition activities may be compacted and lack a topsoil layer.

Urban soil properties have high levels of variability that occur in both horizontal and vertical directions, as well as across site and landscape scales (Effland and Pouyat 1997) and can often change dramatically over short distances. Additionally, individual cities have unique soil types and properties driven by their native soil types, landforms, and development history (Riddle et al. 2022).

Photo 1: A human-altered and human-transported soil profile. Human-transported materials and artifacts, including bricks, are visible in the profile. Photo: Ben Marshall, USDA NRCS.

Soil scientists have established new criteria for describing highly altered soils and have proposed a new soil order, Artesols, that recognize human impacts as a key soil-forming factor. Human-altered and human-transported (HAHT) soils are soils that have been substantially modified by humans for an intended purpose, usually the support of buildings and transportation infrastructure in and around cities (Galbraith and Shaw 2017). HAHT soils often include human artifacts in their profiles and composition, such as cement-building materials and brick (Photo 1). Human-transported materials in HAHT soils may include fill, imported topsoil, gravel, coal ash, or slag. HAHT soils may have homogenized

profiles, truncated profiles that lack specific horizons, or unpredictable layering of horizons in comparison to the native soil types in a region (Herrmann et al. 2018). Despite their high degree of alteration, many HAHT soils demonstrate the capacity to support ecological functions and services in urban areas (Herrmann et al. 2017).

Table 1: Properties of Urban Soils

Physical properties	
Parent materials	Many urban soils are formed from human-transported materials, such as fill, in all or part of the soil profile.
Coarse fragments	High concentrations of coarse fragments are common in many urban soils.
Horizons	Horizons may be homogenized, truncated, or have weak development. Urban soils may also be missing particular horizons, such as A horizons or topsoil.
Spatial Variability	Urban soils tend to have high levels of both horizontal and vertical variability in soil properties.
Chemical properties	
Heavy metals & organic compounds	Increased potential for soil contamination by heavy metals and organic compounds
Nutrient content	Variable nutrient content. Nutrients may be low in soils that have not previously been used for gardening.
pH	Variable pH. Can have alkaline pH from incorporation of cement-based building materials.
Biological properties	
Organic matter and carbon	Variable. Can be extremely high as well as very low, based on site management history.

There are several soil properties and conditions frequently found in urban soils that are distinct from rural agricultural soils (Table 1). Awareness of these properties and determining their presence is key to understanding the function and management of urban sites.

A number of the distinctions are related to unusually high concentrations of a particular property. For example, high concentrations of coarse fragments, such as gravel and construction artifacts, are common in urban soils. These coarse fragments may impact other physical properties, such as water retention and infiltration. When soils contain high amounts of coarse fragments derived from cement-based building materials, the alkaline composition of those materials can result in alkaline soil pH levels.

Alkaline soil pH can present challenges for plant growth and nutrient availability. Urban soils are also found to have soil organic matter levels and nutrient concentrations ranging from very high to very low, depending on management history.

Photo 2: A constructed raised bed in a community garden. The raised bed has been filled with soilless growing media, made primarily from compost. Photo: Valerie Cohen, USDA NRCS

Meanwhile, sites being used for urban agriculture and horticulture often contain an additional type of soil material: constructed garden soils that were imported, or made on site, to improve soil health for plant growth. These created garden soils may be composed largely of organic materials such as compost (Brown 2017) or mixtures of organic waste materials and local soil mineral material generated by construction activities (Araujo et al. 2022; Beniston et al. 2016), or they may be soilless potting media that were purchased elsewhere. Constructed garden soils are commonly used in raised bed gardens (Photo 2) and for planting trees (Chen et al. 2014). Constructed garden soils often provide a significant improvement in ecological function at sites with impaired soil health. Their management and assessment is different from that of more native soil types.

A key consideration for soil health assessment and management in urban areas is to determine which type of soil is present at a site: a more native soil type, an HAHT soil, or some type of created soil or soilless media that has been introduced to the site for gardening.

Soil Health Resource Concerns Found in Urban Soils

Resource concerns, in the context of soil health, are soil conditions that signal a degradation of the soil resource to the extent that it impairs the sustainability and the intended land uses for that soil (USDA NRCS 2019a). Although the condition of urban soils are affected by a variety of resource concerns that cannot be generalized, there are certain soil resource concerns that are commonly found at urban sites (Table 2). When present, these resource concerns decrease soil function and represent a reduced condition of soil health. Identifying these concerns and targeting their remediation through soil health management is vital for maximizing the ecological potential of urban sites.

Table 2: Frequently encountered soil resource concerns in urban areas

Resource concern	Management history associated with resource concern
Compaction	• Use of heavy machinery for construction and demolition of buildings • Concentrated areas of foot traffic
Concentration of salts or other chemicals	• Soil contamination by heavy metals and organic compounds due to industrial land use and use of industrial products • Use of salts on roads
Organic matter depletion, soil organism habitat loss or degradation, and related resource concerns	• Sites with recent construction or demolition activities • Sites where topsoil layer has been removed • Sites where soil has been covered with inorganic materials or kept bare
Unsuitable material and soil sealing*	• Soil surface is dominated by anthropogenic soil property (e.g., coarse fragments) that creates constraints to intended land uses • Soil sealing describes sites where soil has been covered with an impervious surface (e.g., asphalt)

Compaction

Compaction, a process in which pore space is squeezed out of the soil material, inhibits water infiltration, root growth of plants, and microbial activity. Compaction can occur quickly and is a particular concern when soils are wet. It is often caused by the downward force created by vehicles or concentrated foot traffic. This makes it a common resource concern in urban areas, particularly where construction, grading, and demolition activities have occurred. Parked vehicles on lawns around homes and businesses also causes soil compaction to more localized areas of urban sites.

Reduced water infiltration and increased runoff generation are ecological outcomes of soil compaction (Gregory et al 2006). Research has demonstrated that compaction, disturbance level, and vegetative cover are all factors that determine water infiltration rates in urban soils (Kelleher et al. 2020; Shuster et al. 2014; Gregory et al. 2006). Purposefully managing urban soil health for greater infiltration can reduce runoff and lessen demands on stormwater infrastructure (Kelleher et al. 2020).

* Unsuitable material and soil sealing is not a resource concern that is officially recognized by NRCS for conservation planning purposes, but is an impaired soil resource condition that is often found in urban areas.

Compaction can generally be assessed in the field with specialized tools (e.g., a penetrometer) or with visual and tactile indicators of soil hardness, as in the NRCS Cropland In-Field Soil Health Assessment (IFSHA) (USDA NRCS 2019b). Soil compaction is treated in agricultural settings through the application of deep or chisel tillage and by growing vigorous rooting cover crops. Research in urban gardens has confirmed that both compost application and intensive cover cropping are effective strategies for mitigating compaction quickly for urban agriculture (Beniston et al. 2016). Raised beds are effective for eliminating foot traffic that causes compaction and can also provide a more porous material for growing plants on compacted sites.

Concentration of salts and other chemicals

Elevated concentrations of chemicals that are hazardous to human health, including heavy metals such as Lead (Pb) and Cadmium (Cd) and organic compounds such as polycyclic aromatic hydrocarbons and petrochemicals, are the primary chemical concern in urban soils. These chemical concentrations are due to historical use of urban sites for industrial purposes, the historical use of industrial or chemical products, and the atmospheric deposition of chemicals in presently industrial areas. Lead is one of the primary elements of concern in urban soils due to its known impacts on human health. Elevated lead concentrations are common in urban soils, especially at or near the soil surface. The primary risks from lead is the ingestion of soil, either directly or on produce that is not washed thoroughly.

Like other soil properties, the spatial distribution of contaminants can be highly variable in urban areas. Many studies that analyzed lead in urban soils in the U.S. have found that soil lead concentrations were positively correlated with population density, with concentration levels increasing the closer they moved towards city centers and decreasing when moving away (Datko-Williams et al. 2014).

Conducting soil tests for lead and other contaminants during the initial stages of selecting sites and establishing urban agriculture projects is an essential best management practice for soil health (Basta et al. 2021). Guidelines for soil tests often break results into three categories of recommendations: (1) little to no health risk at the site, (2) some health risk, and (3) too high a risk for intended use. However, federal and state guidelines for soil tests are generally designed for residential areas and not agriculture, so test results should be interpreted based on the intended use of the site.

There are various recommendations on managing risk of soil contaminants for urban agriculture. Some advise a conservative approach of assuming that urban sites have contamination risk and using raised beds with created soil for gardens whenever feasible (Paltseva et al. 2022). Others advise determining appropriate management based on soil tests. For sites with low to moderate contamination risk, the recommendations is to add soil organic matter and adjust soil pH to optimal levels with lime, as these practices reduce the bioavailability of lead (Brown et al. 2016). There is, however, a general consensus that soil testing and establishing a cover of vegetation or mulch to act as a barrier on unused areas are best practices for reducing risk (Paltseva et al. 2022).

Organic matter depletion

Like soil compaction, organic matter depletion and the degradation of soil organism habitat are often related to construction and demolition activities in urban areas. Such activities commonly remove topsoil, which is the most biologically rich portion of the soil. Moreover, urban sites may be covered with fill or imported soil or sediment material during these activities. Fill additions may cover topsoil,

import materials with lower organic matter, or arrive as relatively unstructured material. Low organic matter at degraded urban sites is often coupled with soil compaction, which makes it difficult to establish plant cover and biological activity.

Cities in the U.S. have abundant quantities of organic wastes, which provides extensive opportunities for the creation of organic amendments and their application to urban soils (Brown 2017; Beniston and Lal 2012). The smaller scale of urban sites makes the application of large quantities of organic amendments, such as compost and mulch, both logistically and financially feasible. Compost application consistently improves urban soil properties and is an effective remediation when organic matter has been depleted (Cogger 2005).

While depletion of organic matter is a concern for urban soils, many urban sites have soils with high levels of organic C. These carbon-rich urban soils develop in sites with histories of long-term management of perennial vegetation, the import and application of organic amendments, and the absence of topsoil removal (Vasenev and Kuzyakov 2018). Examples of urban sites with high soil C may be found in parks, urban forests, cemeteries, and gardens.

Unsuitable material and soil sealing

A resource concern that is somewhat unique to urban sites is encountering soils that are an unsuitable material for the intended land use. This concern may present in a number of different ways depending on the site history. Soils at these sites have some anthropogenic property that dominates the soil surface condition and makes horticultural land uses difficult or impossible.

One common example are sites where the soil surface is dominated by coarse fragments (e.g., building materials and rocks). This type of soil may be the result of historical demolition practices that did not require removing the construction debris, or due to dumping of materials at the site. Possibly the most extreme form of unsuitable materials at urban sites are sealed soils, where the soil has been completely covered by impervious surfaces. Sites used as parking lots or roadways and covered with asphalt pavement are common examples of sealed sites. Soil sealing can be considered a severe form of land degradation and results in a loss of ecological services from affected sites (Tobias et al. 2018).

Photo 3: Urban farm located in Cleveland, OH. This site is an example of an urban soil with a more native soil type and robust soil health in the surface layer. Photo: Joshua Beniston, USDA NRCS

Common management approaches for sites with unsuitable materials or soil sealing are to import additional materials and remove (i.e., unseal) the impervious surfaces. For urban agriculture, these sites are commonly managed by creating raised garden beds above the surface of the site and importing soil materials to grow plants in, rather than trying to amend the soil at the site. In more broad ecological restoration work, unsealing of impervious surfaces from soils has demonstrated some success in restoring of plant communities but is likely impractical in most urban agriculture settings (Tobias et al. 2018).

Conclusion

Urban soils are vital natural resources that provide important ecosystem services to urban communities. Soil properties and soil health vary widely in urban soils, and their condition is often strongly related to the history of management at the site. Urban sites have the potential to present robust soil health conditions (Photo 3), but they may also be affected by resource concerns. Soil health resource concerns in urban areas include compaction, concentrations of salts and other chemicals, organic matter depletion, and unsuitable materials or soil sealing. These concerns impact the function of urban soils but can often be mitigated through a process of assessment and application of conservation management practices. Understanding and improving the health of soils is important for supporting the health and resilience of urban agriculture and urban ecosystems.

Additional Resources

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L.A. Urban Soil Toolkit – TreePeople (2021)

The Safe Urban Harvests Study – John Hopkins Center for a Livable Future (2021)

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