Evaluation of Urban Soil Suitability

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Introduction

The population in urban areas is predicted to increase globally to 68% by 2050 (UN DESA 2018). In the United States, the expansion into urban areas is higher, with more than 80% of the US population located in these areas (US Census 2010). Soil in these urban areas, known as urban soils, have been drastically altered by anthropogenic activities. These soils tend to lack organic matter, suffer from severe compaction, and may contain construction debris, rendering them unsuitable for cultivation.

There are over 20,000 different soil types across the USA (USDA). When designing projects, engineers can find it useful to know how soils respond and behave in similar situations and uses to those required; similar soils tend to behave in similar ways.

This course will provide a concise and practical overview of the characteristics of urban soils, providing recommendations on how to rehabilitate or recondition them to support green infrastructure or urban agriculture. The principles discussed are applicable to most urban environments.

At the end of this course you will have an understanding of urban soil conditions, be able to assess their suitability, and implement strategies to improve soil quality for green infrastructure and urban agriculture.

Benefits of Green Infrastructure and Urban Agriculture

Engineers can design suitable projects in underutilized or abandoned urban areas when they understand the soils in these urban areas and how they might behave and respond to different conditions. Reconditioning urban soils can improve the fertility of the soil for the creation of green spaces for green infrastructure and urban agriculture. This has many benefits, from increasing the quality of the urban environment and ecosystems, to improving the quality of life of the people in the community.

1. Green Infrastructure

The US Environmental Protection Agency (EPA) defines green infrastructure as “an adaptable term used to describe an array of products, technologies, and practices that use natural systems, or engineered systems that mimic natural processes, to enhance overall environmental quality and provide utility services ”.

Green infrastructure is basically a network of high quality green spaces that includes green roofs, rain gardens, porous and permeable pavements, all of which have been designed to promote biodiversity and ecosystem services. They do this by enhancing or mimicking the natural processes of infiltration, evapotranspiration, and reuse stormwater runoff. Green infrastructure also has added benefits including helping to sequester carbon, filter pollutants, and mitigate urban heat islands by building resilience to extreme climatic events (see Figure 1).

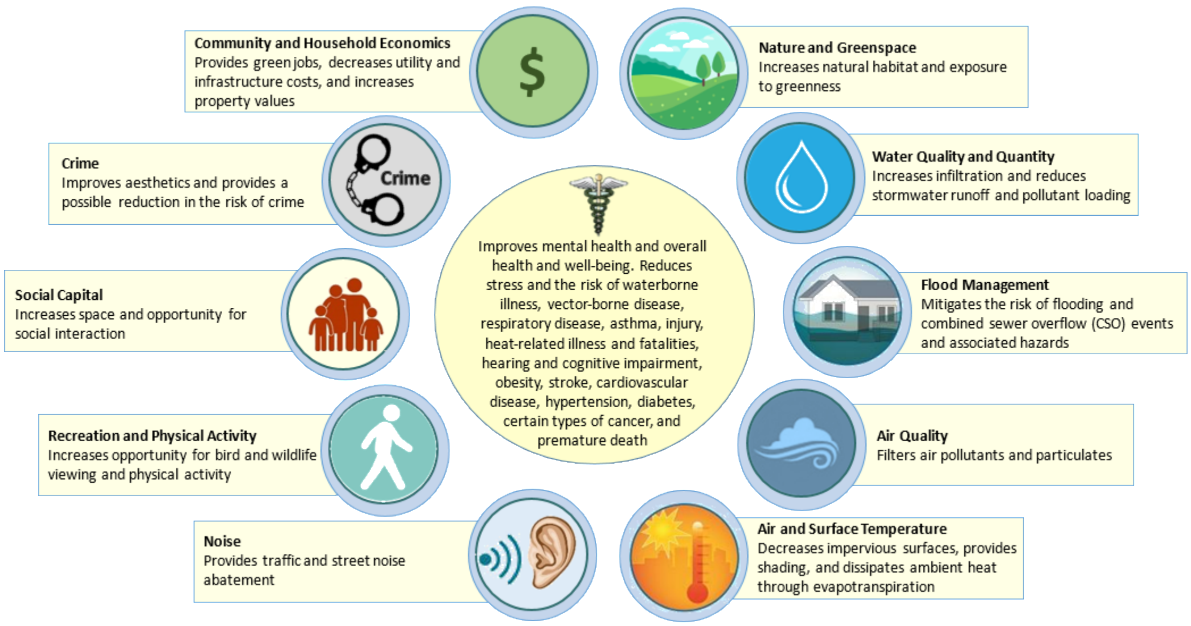

Figure 1. Environmental, social, economic, and public health benefits of green infrastructure. Source EPA 2017

2. Urban Agriculture

Urban agriculture is the community supported growing or producing of agricultural products within urban areas. Figure 2 is an example of an urban agriculture site in downtown St. Louis, USA. The cultivated crops may be used for local consumption or sale. Like green infrastructure, urban agriculture has many benefits such as providing nutritious food, reducing urban heat, and improving the quality of life for the to the community.

Figure 2. Example of urban agriculture in downtown St.Louis. Image by Oztafi US.

Urban Soils Characteristics

Soil refers to the loose mineral or organic material found on the Earth's surface, providing a natural medium for plant growth. Soil properties are shaped by various factors, including climate and the actions of macro- and microorganism, that transform the parent material over time.

In urban areas, soils on individual parcels within metropolitan regions are often affected by human activities. These soils have generally been disturbed, graded or compacted due to construction and demolition activities. The movement and mixing of soil profiles, or the introduction of non-native soils, are common occurrences in these developed areas. As land is filled or hills are graded by fill materials, often sourced from nearby areas, soils are shifted and relocated. Consequently, the characteristics of soils within an urban land parcel can vary significantly and have different characteristics than the native soils on-site.

Studies conducted in urban areas have identified common attributes of urban soils, including:

- soil compaction
- low organic matter content, and

- low levels of contamination typically originating from airborne deposition or historical site uses.

Assessing soil quality in urban areas involves addressing two key aspects: the suitability of the soil as a growth medium and the potential presence of contaminants.

Understanding the historical background of a vacant land parcel can offer valuable insights into potential soil contamination. Industrial areas may have a history of contaminants like chemicals utilized in manufacturing, heavy metals and hydrocarbons. Residential areas constructed before the early 1980s commonly have contaminates such as asbestos, lead paint residues, coal and wood ash deposits, fuel and motor oil residues, and pesticides. In addition, abandoned septic systems, cistern and wells are frequently uncovered during the development of these sites. Generally, residential areas exhibit less compaction and higher soil quality compared to more heavily urbanized regions. Therefore, knowledge of a parcel's development history is crucial in determining the appropriate soil testing requirements, if indeed there are any, before embarking on redevelopment or reuse efforts.

Brownfields are previously developed sites that are now abandoned or underutilized. These vacant sites are available for redevelopment, however, they pose complexities due to potential or existing soil and/or groundwater contamination. The U.S. EPA's Brownfield Program, as well as those of many state agencies, offer funding opportunities in the form of loans and grants for assessing and cleaning up Brownfields. Many cities have successfully remediated Brownfields as well as other vacant sites, transforming them into community gardens and stormwater parks (U.S. EPA, 2009).

Evaluation for Site Suitability

Before any remediation of urban sites for the creation of green infrastructure and urban agriculture can begin, the suitability of the site must first be evaluated. The site's suitability will be dependent on the goals for its redevelopment, and must also take into account the impact on human health.

Urban sites with relatively low levels of historical contamination that are considered for reuse into community gardens or stormwater parks will have a relatively low risk to human health. More specific evaluation of human risks should be done for sites that are to be redeveloped for urban agriculture. This is because people will not only come into direct contact with the soil when growing the produce, but will also be eating the food produced. Consideration should always be taken of the risks to the workers developing these sites.

Site suitability will be dependent on the type of plants the urban soils will need to support for its reuse purpose. For example, when evaluating soil quality for green infrastructure or infiltration, assessments should focus on the soil's role as a growing medium for plants, its water storage capacity, water infiltration potential, and the likelihood of contaminants being mobilized or migrating through the soil. On the other hand, when evaluating soil quality for urban agriculture, specific tests should be conducted to determine if the desired crops can thrive and to assess the potential uptake of contaminants by the plants intended for consumption.

1. Characterization of Urban Site and Soils

Once the proposed redevelopment plan of the urban site has been determined, the next step is the characterization of the site and soils. This involves reviewing any available records as well as visiting the site to assess its historical, chemical, biological and physical characteristics.

2. Historical Use of Urban Site

It is important to assess the historical use of the urban site to determine the potential for contamination at the site. For example, if the site has been exclusively used for residential housing since the area's development, then the potential of significant soil contamination is lower compared to a site located in an industrial area.

The Phase 1 Environmental Site Assessment (ASTM E1527-05) is a standard comprehensive process for evaluating a site's historical use and potential environmental concerns. This assessment involves gathering information through interviews with neighbors, local city officials or previous property owners, as well as attempting to obtain old aerial photographs or maps of the area. Valuable data can be obtained from various sources including soil surveys from local conservation district offices, permits from city halls, tax records from county offices, and photographs and hand-drawn site maps from libraries, historical societies and preservation offices. Conducting a Phase 1 Environmental Site Assessment will frequently include reviewing public land ownership records and environmental databases. If potential environmental concerns are identified during the Phase I Environmental Site Assessment, then further data collection in the field is necessary; known as a Phase II Environmental Site Assessment (ASTM E1903).

3. On-Site Field Assessment

Doing a site visit and field assessment is crucial for guiding future activities. It is important to take detailed notes and photographs during the visit for later work. An example of a field sheet can be found in the Urban Watershed Forestry Manual, Part 3: Urban Tree Planting Guide (USDA, 2006).

The history of the site should serve as a guide during the field visit. If the records indicate the presence of a previous structure, the site visitor can use local landmarks to help locate its former position. Additional, if any surface remediation has taken place, then it might be visible. Previously obtained current and historical aerial photographs can also be useful to verify the accuracy of the imagery and aid the on-the-ground analysis.

During the field assessment, it is essential to document the presence of existing utilities. Underground and above ground utilities can present hazards and may impose limitations on the site's restoration or future use. Statewide utility locator companies, such as the Ohio Utilities Protection Service in Ohio, are typically used to identify public utilities. Private utilities must be identified either by the property owner or by referencing plans and maps.

Both urban agriculture and stormwater management practices require thorough assessment of the urban site's topographic, hydrologic and biological conditions. This includes identifying existing drainage patterns, determining the general slope of the site, and locating areas of concentrated flow or erosion. Evaluating the contributing drainage area or watershed is necessary to understand how higher levels of paved areas or impervious surfaces can generate larger volumes of runoff and peak flows that may impact the site. In addition, it is also important to identify the presence of wetlands and areas of depressional storage. Assessing soil type should also be done to determine its potential for infiltration.

There are various methods to assess the soil compaction on an urban site, from visual observations and field measurements to laboratory analyses. Sufficient information to determine the need for soil reconditioning can usually be obtained from visual observations alone. Signs of soil compaction include poor plant growth at the surface, as well as the lack of roots or limited biological activity within the soil profile. If required, laboratory and field tests can be conducted by professionals. In addition, the relative proportions of different soil particle sizes can be assessed in the field or analyzed in a laboratory through grain size and hydrometer analysis.

Vacant sites that have recently undergone demolition are likely to contain a substantial amount of construction debris and fill material. The demolition work itself could have further compacted the soil at the site. It is also possible that remnants of basement foundations may still exist several feet below the surface, potentially filled with additional materials. It is, therefore, important to identify any remaining structures or traces of structures as they could potentially impact construction costs and the performance of future green infrastructures.

It is highly recommended that soil sampling is conducted as part of the field assessment to determine the suitability of the soil as a growing medium. Soil tests should at the very least include pH levels, percentage of organic matter, nutrient content, micronutrients and concentration of metals, particularly lead. The USDA Cooperative Extension System offices, as well as various local private universities and land grant universities, offer local soil testing information or services.

Evaluation of Soil Suitability

It is crucial to determine the health of the soil and its ability to support the growth of the desired plants. Which strategies are necessary to improve the soil will vary depending on the purposed use of the site. For green infrastructures, soil suitability evaluations should focus on its ability to support growth of native plants or ornamental vegetation, as well as the soil's capacity to retain and infiltrate stormwater runoff. At sites intended for urban agriculture, the nutrient levels in the soil and ability to sustain desired crops is more important. The physical, chemical and biological conditions as well as the characterization of the soil should all be considered and assessed to determine the reconditioning needs of the soil.

1. Soil Texture

Soil texture effects the water-holding capacity and permeability (see Table 1), which is especially important when designing and constructing a variety of stormwater practices, as well as the soil's workability and ability to allow plants to grow.

Table 1. Permeability water retention of different soils

Soil texture	Permeability	Water Retention
Sand	High	Low
Loam	Medium	Medium
Clay	Low	High
Silt	Low	High

Adapted from Davis, J.G. (2013).

The USDA's Texture Triangle in Figure 3 below is used to classify soil texture based on the relative sand, silt and clay content. It is common to use a mixture of sand, topsoil and compost as soil amendment for green infrastructure.

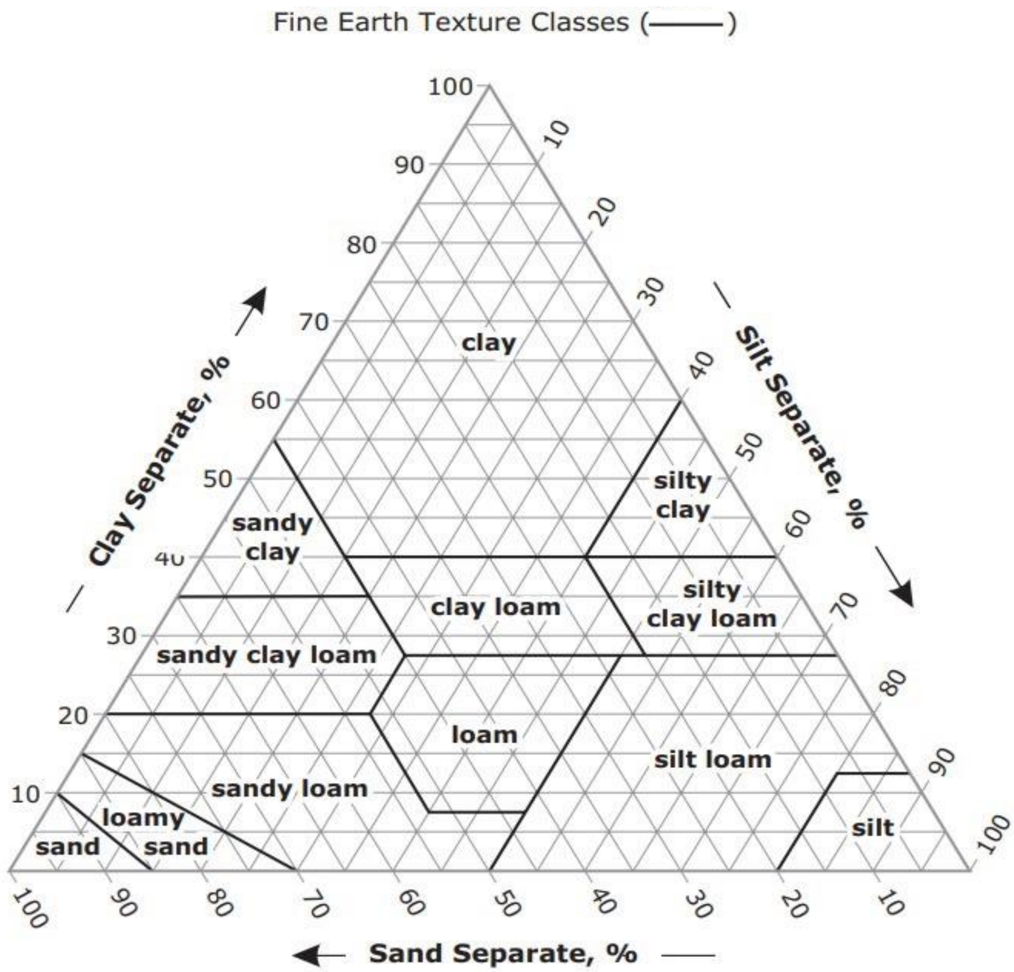

Figure 3. Soil Texture Triangle based on USDA particle size.

Sandy soils are well aerated, so less likely to be severely compacted. They have high water infiltration rates, making them ideal for green infrastructure with stormwater runoff. However, they tend to have low nutrient levels. Therefore, amendments to sandy soils are needed to add organic materials to support vegetation, and to ensure storm water is free of high sediment loads.

Loamy soils contain a mixture of sand, silt and clay, and exhibit each of their properties equally. This type of soil is friable, soft and rich in organic matter and so is the ideal soil for growing food crops, but this also makes them prone to compaction as well as wind and water erosion. Water drainage and infiltration will depend on the relative silt and clay content, however, drainage in uncompacted loamy soils usually provides sufficient moisture for plant growth.

Clayey soils consist of fine particles of clay that provide very good water retention, cohesiveness, and a unique ability to resist wind erosion, though water erosion can be severe. Clay soils have poor drainage and are easily compacted by both human activity and natural phenomena. The clay swells when wet and shrinks when dry, and will require aeration or soil amendments to support plant growth.

2. Soil Structure

Soil is made up of distinct layers called horizons, with rich organic upper layers (humus and topsoil), to rocky subsoil and bedrock, as illustrated in Figure 4 below.

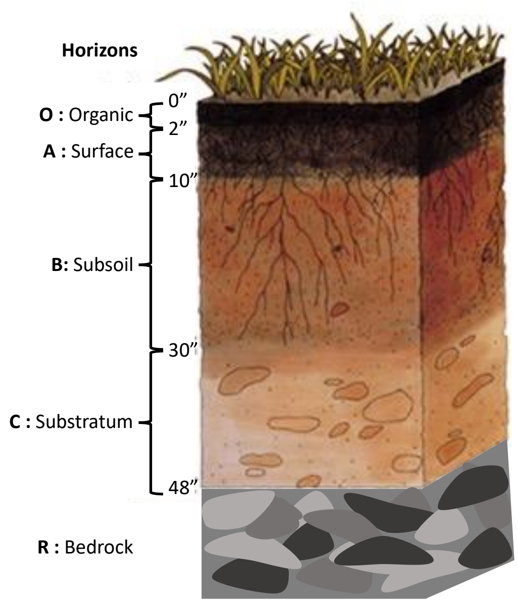

Figure 4. Arrangement horizon in the soil that make up a soil’s profile. Adapted from USDA

3. Components of Soil

Soils are made up of air, water, organic matter (living and/or dead) and mineral matter (sand, silt, and clay). Urban soils will also include man-made materials. The percentage of each of these components can vary dramatically on the same site.

Soil particles are arranged in aggregates with pore spaces that allow air and water to penetrate between them. Air spaces between the soil particles allow for moisture buffering and temperature insulation. The structure of the soil is preserved when protected from erosion, compaction and other disturbing activities.

Grading, filing, construction and demolition activities, and the absence of plants with deep roots, can lead to the deterioration of soil structure. This will result in decreased aeration, water retention, biological activity, and root penetration, as well as reduced uptake or water and nutrients by plants.

Figure 4 illustrates the general composition of natural soil (A) and compacted soil (B). As the soil particles are compacted together, the pore spaces are reduced (see Figure 4C), and this will change how the soil is able to retain and handle water movement through its horizons.

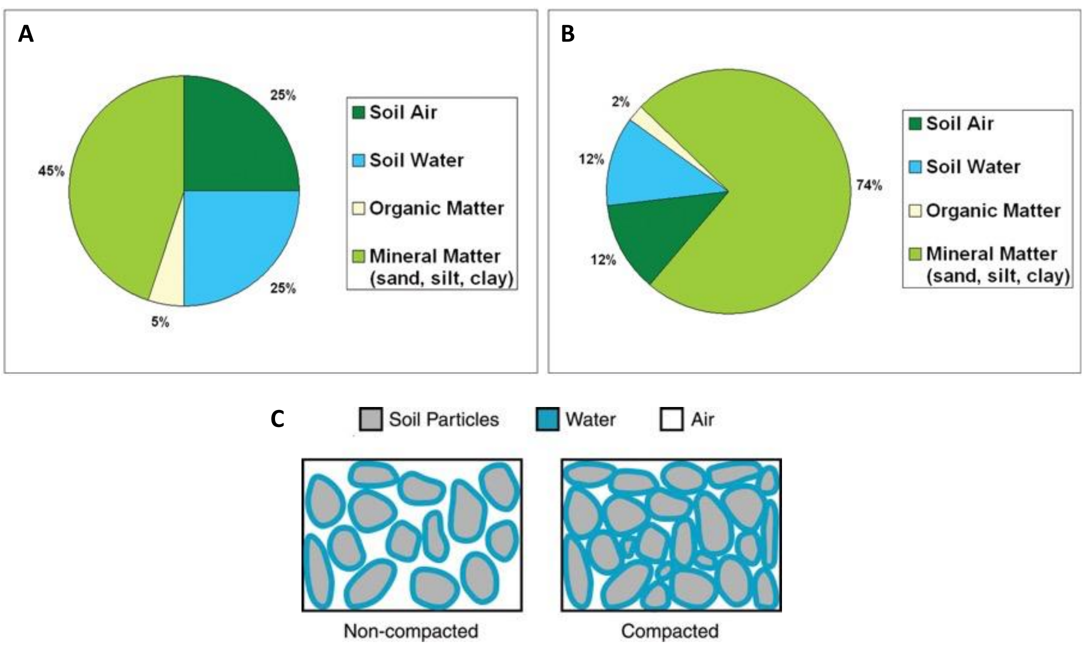

Figure 5. General composition of natural soil (A) and compacted soil (B), and the effect of compaction on pore spaces (C). Adapted from Scheyer, J.M and Hipple, K.W. 2005.

The compaction of the soil by the pressure of heavy traffic, tillage practices, water or construction activities will collapse the pore spaces between the soil particles. Compacted soils are denser with soil temperature extremes, making areas of the soil unnaturally dry or oversaturated and unable to support plant growth. More heavily compacted areas prevent water and air movement, and can emulate impervious surfaces by exhibiting stormwater runoff characteristics.

4. Soil Moisture

Soil moisture is the total amount of water within the pores or on the soil surface as precipitation. Infiltration of water will be dependent on the size, amount and distribution of pore spaces with the soil. For example, sandy soils, with rounded particles, have a higher permeability than clayey soils as water and air cannot move as easily through the clay's flat particles. It is dependent on the interconnectedness of the pore spaces. Soil porosity refers to the ratio of the pore space volume to the total volume of soil, and is particularly important for crop production in urban agriculture.

Any soil remediation and plant selection should take into account both the permeability and porosity of the existing soils (refer to Table 1). A sandy soil can be highly permeable with less porosity, thus limiting its moisture retention but allowing for good drainage. While a clayey soil can have high porosity and low permeability due to the large volume of pore spaces that are not interconnected.

Soil moisture content is also an important factor. Water movement in the soil is best observed straight after a soaking thunderstorm or as the snow melts after the ground has thawed. Results should be recorded over several hours and days, and note when the soil surface starts to dry, and if there is any standing water left in the root zone (12 – 18 inches deep). During spring and summer when the weather has longer drier periods, water retention can be better observed. This can highlight any unusual saturation areas that may be caused by a clogged drainage system, a leaking subterranean pipe, or other soil features.

Further simple tests can determine if the soil characteristics can support plant growth. Squeezing a handful of soil taken from about 6 inches deep can be used as a screening-level assessment to evaluate the soil's moisture (though it will not work for very sandy soils). If the soil remains in a ball after squeezing with the appearance of a wet outline of water, then the soil is very moist. If the ball breaks apart but stays in large clumps, then the soil is moist. The time it takes water to leave the root zone should also be assessed. This is done by digging a hole 12 – 18 inches to reach the root zone, and filling it with about three inches of water. Drainage of the water within 15 – 20 minutes indicates that the soil is suitable for the growth of most plants and root crops. If it takes longer for the water to drain, between 30 minutes to eight hours, then the soil is more suitable for general woody and grass species. If, however, the water has not drained after eight hours, then the drainage will need to be modified if it is support any plant growth other than wetland.

5. Soil Chemistry

Soil chemistry looks at the chemical characteristics of the soil by studying the chemical composition and properties. It also looks at the chemical reactions of soils with nutrients (organic matter), contaminants, air and water, as well as interactions with plants and soil organisms. These interactions can be complex, and will be greatly dependent on the temperature and biological activity in the soil. Therefore, it is particularly important to test the soil chemistry when using the site for urban agriculture and the growth of food products. The type and presence of nutrients, inorganic materials, contaminants, and soil pH will all greatly influence the suitability of the soil as a growing medium. In addition, all soil chemical reactions require water, and many are effected by oxygen and other air gases.
Soil testing typically includes standard parameters such as soil pH, potassium, phosphorous, lime index (calcium and magnesium), and cation exchange capacity, which indicates the soil's potential for holding nutrients. Additional tests commonly offered include nitrogen (total nitrogen, nitrate and ammonium), heavy metals (aluminum, arsenic, cadmium, lead and mercury), salinity, and micronutrients which may vary depending on the region.

The availability of nutrients for plants is primarily influenced by the pH of the soil as plants can only absorb nutrients that are dissolved in the soil solution and in contact with the surface of the roots. The pH is a measure of the acidity or alkalinity of a solution or substance and the optimal pH range in soils is between 6.0 – 7.5 (see Figure 6). Soils with low pH (acidic soils) can lead to the accumulation of certain elements in the soil, while high pH soils (more alkaline soils) can hinder chemical uptake by plants. In the Great Lakes, the native soil has a pH range between 6.0 – 8.0 which supports the growth of most plants and soil microorganisms. They also have a significant buffering capacity, allowing them to withstand rapid pH changes due to the naturally high levels of silt, clay or organic matter in the soil. However, in urban sites the soil pH may be effected by lime leaching from concrete and masonry construction resulting in increased soil pH levels.

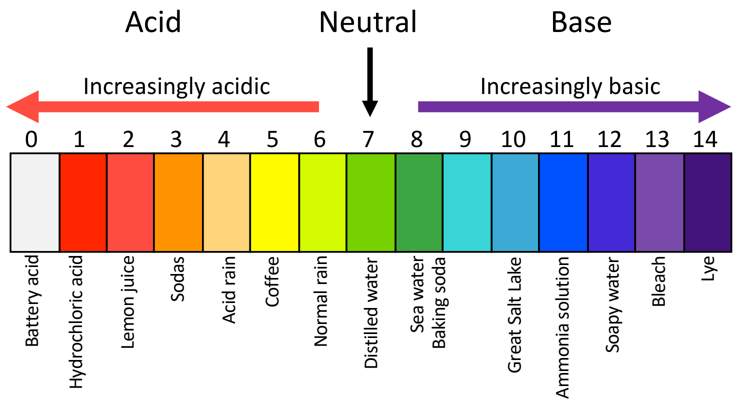

Figure 6. The pH scale. Copyright Dr.Jeelan Moghraby

Information about local soil testing laboratories can be obtained from the State Cooperative Extension Services offices and various land grant universities. For example, the University of Massachusetts at Amherst offers a range of soil tests to assess the suitability of the soils at the site for green infrastructure or urban agriculture projects. Tests like the Soil Texture Test to classify the soil according to the USDA Textural Classification (as described above) is generally used for assessing green agricultural sites. Soils tests measuring the pH, nutrients or metals can be used to evaluate soil suitability for urban agriculture.

While the primary focus of this course is to assess and restore soils to support optimal plant growth, it is also important to evaluate potential contaminants. Touching and working with contaminated soils can pose health risks. In urban agricultural sites, consuming food grown in contaminated soils can be hazardous. Root vegetables, in particular, may need additional attention and caution compared to above ground fruiting plants or perennial crops due to the higher potential for uptake, as well as the increased interactions by workers with the soil. It is advisable to investigate the history of the urban site and, if necessary, seek guidance from local or state Brownfield authorities when assessing a site's suitability for green infrastructure or urban agriculture projects.

6. Biological characteristics of Soils

Factors such as land use, drainage, and contamination can lead to variation in the biological characteristics of urban soils. When conducting a site visit, the quality of the soil can be assessed by examining the plants that are growing there, taking a note of their species and overall health. Various plant species can provide insights into specific soils and so can indicate the condition of the soil; consulting local experts would help to determine what these different species suggest about the soil's condition. In addition, established large trees at the site can serve as valuable long-term indicators of soil conditions (Urban, 2008).

Where there is little or no plant growth, soil odors can help to indicate the biological activity of the soil. Healthy soils with good microbial activity and aerated organic matter have an earthy odor, while soils with no or poor microbial activity have little or no odor. If the soil has a putrid or sour odor, it would suggest that the soil has remained wet for a long time, or compost that was not properly processed was applied.

Another good indicator of soil conditions is the presence of earthworms. Good soil conditions have healthy earthworms. Anemic-looking or thin earthworks suggest that the soil is lacking nutrients or organic matter. And if there are no earthworms, the soil is likely to be compacted, or, in the case of friable soils, contaminated with heavy metals or chemicals, or contain extremely low organic matter.

At urban sites, the natural process that contributes to soil organic matter formation are often disrupted. Various features of urbanization such as pavements, removal of plant debris like leaves and grass clippings, and tree branch removal, hinder the recycling of organic matter and nutrients back into the soil. Without the decomposition of plant materials, the persistence of microorganisms in the soil is affected. The restoration of urban soils, especially for supporting green infrastructure and urban agriculture, will, therefore, usually require increasing the amount of organic matter in the soil.

7. Strategies to Address Unsuitable Soils

When preliminary evaluations conclude that the site's soil is unsuitable for its intended purpose, it is often possible to improve the condition of the soils. This usually requires multiple strategies, with relatively larger effects at the start of reconditioning, and further smaller efforts over time. However, if reconditioning of the soil is not feasible, for example because of the presence of contamination that prohibits the use of the soil, then changing the use of the site may be an alternative.

Where the soil is contaminated at the surface or root zone, raised planting beds and vertical gardening for urban agriculture are alternatives. Importing clean soils and using mulch around the raised planting beds as a porous barrier, is a cost effective way of creating an urban community green infrastructure on an otherwise unsuitable soil site. In some cases, it may be at least possible to plant hearty native plants on the site's soil that are aesthetically pleasing to the local landscape.

Reconditioning of Urban Soils

The reconditioning of urban soils is dependent on the intended use of the site. The aim is to enhance the ability of the soil to support the different plants and infiltrate stormwater. Sites that will be used for green infrastructure and stormwater management, for example, will need to have the soil modified to increase infiltration and support the growth of the selected plants. More work will be needed if the site is to be used for urban agriculture to ensure that the soil can support the crops and plants required. In the long-term, reconditioning of urban soils can be achieved by using compost and mulch to provide nutrients, and planting to provide additional erosion control.

1. Types of Reconditioning

Reconditioning is the process of adding materials to the soil to change and improve its properties. The types of reconditioning can be physical, chemical or biological, and are generally performed in that order.

Physical reconditioning methods include mitigation of compaction, improving the structure of the soil, and altering the drainage characteristics to suit the intended purpose of the site. Chemical reconditioning involves changing the soil chemistry to the required parameters. This should only be done after the soil samples collected in the field assessment have been assessed in a laboratory. Subsequent testing should be done after any chemical reconditioning to determine if it was successful and whether further reconditioning is necessary. Biological reconditioning follows physical and chemical reconditioning as they both are needed to help prepare the soil ecosystem to support the organisms used to change the soils characteristics.

The most common methods for each type of soil reconditioning are summarized in Table 2 below.

Table 2. Types of Urban Soil Reconditioning. Copyright Dr.Jeelan Moghraby.

Physical	Chemical	Biological
• Soil removal • Raking • Tillage and subsoiling • Soil amendments and additives	• Soil amendments and additives • Mulch	• Soil amendments and additives • Mulch • Recyclers • Cover crops

2. Soil Removal

Soil Removal is the excavation and removal of the contaminated soil for disposal. This tends to be a more expensive reconditioning technique, but necessary if the level of contamination in the soil means that it cannot simply be capped on site.

3. Raking

Raking is used for the removal of debris, especially in vacant parcels following demolition where there is extensive rocks and rubble. As well as efficiently collecting small rocks as small as ¾ of an inch, the act of raking will also level up the soil. Raking can either be performed by hand when the site area is relatively small, or by using landscape rakes attached to a compact tractor.

4. Tillage and Subsoiling

Tillage involves the mechanical breakage and turning over of compacted soil. Compaction of soils is common in urban sites as a result of construction or demolition, usually in the top 12 to 24 inches of soil, and in the root zone of most plants.

Subsoiling, also known as deep tillage, is more commonly used at agricultural sites to minimize soil compaction deeper in the soil, from three to eight feet, and recreate soil structure. It involves ripping or scarification of the soils in a gridded pattern to create air and water pore spaces and flow paths. Subsoiling can be used with other tillage techniques. Tillage and subsoiling will usually only be needed to be done once to mitigate soil compaction, followed by stabilization of the newly exposed soils to prevent erosion.

The freezing and thawing of soils in urban areas can also be effective in breaking up the soil. By plowing in the fall, as the water in the soil freezes and expands, it acts as a wedge to break clods of soil. And when the water thaws, it leaves pore spaces allowing in air and supporting microorganisms. Combined with tillage, this method not only improves soil condition and better water infiltration, but also kills weed seeds, insects and pathogens.

5. Drainage

Proper drainage is important for any green infrastructure or urban agriculture site. All plants require a specific soil moisture range in order to thrive, and soil drainage is used to encourage this healthy root environment. Surface drainage can be amended by grading, excavating and restricting drainage outlets to increase the infiltration capacity of the soil and its moisture. Modification of the soils should be done to the correct root zone of the selected plants, however, if drainage is difficult, then alternative plants could be used.

6. Soil Amendments and Additives

The physical characteristics of urban soils can be altered by adding soil amendments and additives. Of course any such material that is to be added should be of known origin and quality to help guard against disease, allergens and unwanted chemical or seeds.

Some of the benefits of using soil amendments include:

- Restoring the health and structure of the soil to support plant growth and ecological function
- Improving soil drainage and stabilizing the soil to prevent erosion
- Reducing bioavailability and leachability of contaminant
- Lowering cost compared with other remediation techniques

There are five main types of soil amendments; organic, mineral, physical, chemical, and biological.

7. Organic amendments

Many organic amendments and additives are usually derived from plant nutrients. They act to increase the organic content in the soil by providing essential nutrients (such as carbon, nitrogen and phosphate) to re-establish growth. Other direct benefits include supporting plant growth and microbial activity, as well as improving soil aeration, chemical buffering, and cation exchange capacity of the soil.

The most commonly used organic soil amendments is compost (see Figure 7), as it stimulates biological activity as well as providing plant-protection benefits. As compost is not regulated and the quality can vary considerably between suppliers, it is best to use the US Composting Council established standards to ensure that a high quality compost is used on site.

Figure 7. Compost, an example of an organic amendment used for green infrastructure projects. Image by Norman ack.

Compost can be made from household food scraps like vegetable waste, leftover meals, stale breads, coffee grounds, tea bags, and general food spoilage. These should not be directly applied to the soil or tilled. To properly convert these organic materials into compost and limit the risk of introducing noxious weed seeds and other undesirable matter such as insect eggs to the new site, they should be secured in a bin while they degrade to keep out rodents and scavengers. However, using compost will not eliminate all pesticides or chemical residues.

Other examples of organic amendments include manure with a higher nitrogen content than compost, peat, wood chips, and biosolids.

Organic amendments will require proper aeration due to their abundant levels of moisture and water retention. Because of this, they are not suitable for improving drainage in compacted or other soils where excess water cannot move from the root zone.

8. Mineral amendments

Mineral amendments are inorganic materials that are usually mined or man-made. They play a vital role in soil improvement by enhancing drainage and stability over an extended period when applied in sufficient quantities.

Three effective mineral amendments suitable for soil mixing are perlite, haydite and pumice (see Figure 7). All three possess ample internal pore spaces that efficiently retain air and water, creating optimal conditions for plant growth, as well as being chemically stable and sterile. Perlite is derived from steam expanded volcanic rock, comes in different grades, and can be used for a wide variety of applications. Haydite is a porous and inert clay product formed through high-temperature baking, and pumice is a lightweight, foamy volcanic rock.

Figure 8. Perlite, haydite and pumice are excellent mineral amendments used for soil mixing. Images from Depositphotos.com

Another excellent soil additive providing many benefits for soils is powdered charcoal. It is chemically stable, has the ability to absorb various chemicals, stabilizes pH and has a high cation exchange capacity, as well as stimulating secondary biological activity. Other examples of mineral amendments that provide increased moisture retention for the soil include calcine clay, expanded shale, clay and slate, and vermiculites. The latter is not recommended for urban agricultural use.

To improving drainage in green infrastructure and drainage structures, gravel and sand are usually recommended. For example, in rain gardens and bioretention facilities, a mixture of sand, compost and topsoil is usually used to amend the soil. Other filtration practices, such as rain gardens with underdrains (biofiltration) can also use sand and gravel. However, just the addition of sand and gravel is usually not sufficient to improve the infiltration capacity in clayey soils.

9. Physical amendments

Soil stabilizer grids, geo-webs and turf cells are examples of structures that are added to stabilize loosely compacted soil within the root zone. These physical amendments are more suitable for green infrastructures such as permeable parking areas, where they can support loads or control erosion, and for stabilizing soils for small plants and grasses. They are not suitable for urban agriculture.

10. Biological amendments

Biological soil amendments are derived from biological materials and play a crucial role in enhancing the soil ecosystem by improving the soil food web. They include microfauna and macrofauna which break down organic material to promote plant health, nutrient cycling and disease suppression. For example, mycorrhizae is a fungus that establishes a symbiotic relationship with the plant roots, helping to increase the plant's nutrient and water uptake.

The most important macrofauna due their abundance and benefits to the soil are earthworms, termites and ants. These organisms burrow in the soil, enhancing drainage, aeration, and organic matter incorporation. They consume decaying plant material, contributing to nutrient cycling, and their burrows promote root growth and nutrient access.

Earthworms, in particular, are highly effective, as they burrow deeper into the soil (up to several feet) ingesting and processing soil particles, and leaving behind castings that improve soil structure and nutrient penetration. They can also change the soil chemistry (pH and cation exchange capacity), efficiently bury seeds and organic debris, detoxify contaminants such as petrochemicals, alter heavy metal bioavailability, promote growth and dissemination of microorganisms, and create macropore spaces for microfauna and root penetration. Using earthworms to recondition and improve urban soils is a promising technology. However, to establish thriving earthworm populations, compacted, rocky, biologically depleted, excessively wet, or dry soils may require modification. In addition, selection of the appropriate species is important. For instance, though "red worms" are used for composting, they do not thrive in soil. On the other hand, bait worms and night crawlers thrive in soil but are less efficient in composters.

Other examples of biological amendments include kelp extracts, that provides trace minerals and nutrients, humic acid, which stimulates microbial activity and nutrient uptake, and compost tea, which adds soluble nutrients and inoculates microbial life.

11. Chemical amendments

Chemical amendments, often in the form of fertilizers, aim to change the soil chemistry by altering the nutrient levels or pH of the soil. When chemical amendment they should be matched with the growth phases of the selected plants. This is a challenging task and should only be considered after the soil has undergone physical reconditioning using the methods described above. In addition, it is important to have first analyzed the existing soil chemistry at the urban site and selected the appropriate chemicals. This is to avoid or minimize potential side-effects, such as soil salinization. The minimum amount of fertilizer should be used to achieve the desired outcome of correcting the chemical imbalance in the soil. This is particularly important because many fertilizers contain phosphorous, often a limiting nutrient in waterways. Excessive use of fertilizers can lead to excessive algae growth in lakes, stream and ponds, disrupting the ecological balance. Once the plants are established, chemical fertilization are often no longer needed. Table 3 below is a summary of the characteristics of the urban soil and the threshold for the various soil properties. This will vary with soil type and region. Soil reconditioning is recommended if the moderately impacted threshold for a given soil parameter is exceeded, and will be required for those exceeding the severely impacted thresholds. In most case, the addition of compost and/or peat would improve the impacted urban soils, while the pH of urban acidic soils can be corrected by adding lime.

Table 3. Impacted Thresholds for Soil Parameters in Urban Soils

Soil Characteristic	**Moderately Impacted Threshold**	**Severely Impacted Threshold**
Percentage sand	>75	>90
Percentage clay and silt	>50	>75
Bulk density of clay (mg/m^3)	<1.4	>1.5
Bulk density of loam (mg/m^3)	>1.5	>1.7
Infiltration, percolation, and permeability rates (in/hr)	<0.25	<0.20
Depth of bedrock (ft)	<4	<2
Acidic soils (pH)	<6	<4
Alkaline soils (pH)	>7.5	>8.5
Cation exchange capacity (meg/100g)	>5	<3
Potassium (Ibs/acre)	<44	
Phosphorous (Ibs/acre)	<124	
Percentage organic matter	<1	
Soluble salts (ppm)	600	1,000

Adapted from USDA (2006).

12. Cover Crops

Cover crops provide a wide variety of benefits to urban soils that accumulate over time. Benefits include:

- Enhancing nutrient and moisture availability
- Creation of organic matter and stimulate biological activity
- Improving soil quality and health
- Inhibiting weed species
- Buffering temperature and pH
- Slowing of erosion
- Reducing costs and increasing profits
- Replacing the need for fertilizers
- Highlight troublesome areas missed by spot tests

Planting of cover crops is relatively easy and inexpensive. Before spending on expensive planting needed for the intended green infrastructure, it makes good fiscal sense to use cover crops first to ensure the characteristics of the urban soil can support the plants. It would also allow more time to properly plan for the intended use of the urban site.

Choosing the right cover crops will be dependent of the desired benefit, location and season. For example, winter cover crops such as clover, oats and rye, provide good soil cover. On the other hand, summer cover crops, also known as green manure, are usually chosen for their ability to improve poor soil conditions or prepare the site for a perennial crop. Soybeans is an example of a summer cover crop that adds nitrogen and organic matter back into the soil.

A living mulch can act as a crop cover, and is interplanted with a main annual or perennial cash crop. They are usually grown between rows of the cash crop to suppress weeds, protect against erosion and provide traction, source of organic matter and nutrients, and improve water infiltration. To avoid competition with the cash crop, living mulches can be chemically or mechanically suppressed. Living mulches used for annual cropping systems include hairy vetch overseeded into corn at the last cultivation, no-till planting of vegetables into subterranean clover (or subclover), sweetclover drilled (for precise seed-to-soil contact) into small grains, and annual ryegrass broadcast (seeds sprinkled lightly over soil) into vegetables. Grasses or legumes planted between the rows of cash crops are used as living mulches in perennial cropping systems.

13. Mulch

Mulch can either be organic, like shredded bark, leaf mulch or wood chips, or inorganic (synthetic), such as shredded tires or paper, sheet plastic, and crushed glass (see Figure 9). The mulch is left on the surface of the soil and acts to reduce water evaporation and runoff, moderate soil and plant root temperature, reduce erosion, reduce light soil compaction, and inhibit weed growth. Organic mulches will also replenish organic matter in the soil, thereby enhancing biodiversity and nutrient cycling to help plants and soil organisms grow. Mulches can also be used as walking paths in urban agriculture and green infrastructural sites, improving the aesthetic value.

Figure 9. Example of community used mulch. Images from Depositphotos.com

Organic non-living mulches are most commonly used as they are easily obtained and readily decompose. As they decompose, they slowly release nutrients into the soil. Mulching twice a year, in late spring and during leaf fall, will help to maintain its benefits as a soil amendment. The mulch should also be checked regularly to maintain a depth between two inches (for poorly drained sites) to four inches (for well-drained sites; USDA, 2006). Using the proper thickness helps to keep the underlying soil moist and cool during the summer months, and above freezing in the winter.

Overuse of mulches can be harmful to the soil and may even kill established trees and shrubs at the site. If the non-living mulch is not intended as a growth medium, then anything above two inches can lead to soil anoxia which can cause biological degradation, as well as becoming a home for detrimental animals. In addition, slowly decomposing organic mulches with fine structures, such as cypress mulch, while needing fewer applications, can act as a water and air impermeable barrier. If the mulch is not mechanically disturbed over time, it can lead to the introduction of disease, chemicals, allergens and unwanted seeds.

As with any soil amendment, it is important to research and match the appropriate mulch with the desired plants and crops, as well as the climate. For example, in warmer and drier climates, mulches become less effective in helping soil to recover from light compaction or shallow surficial compaction. This is also the case as biological activity decreases and root penetration diminishes. Each type of mulch will have its advantages and disadvantages, and must be managed properly so as to enhance overall growth, yield and quality. Though the use of inorganic mulches has increased, organic mulches are preferable as they can provide water and nutrients to the plant root zone.

Bioremediation

Bioremediation involves leveraging the natural abilities of plants and microorganisms to break down organic contaminants and convert them into harmless by products. It typically involves the application of compost or soil amendments to enhance microbial action and facilitate the degradation of harmful chemicals like gasoline or oil (U.S. EPA 2001a). The successful implementation of bioremediation requires synergy across the plants, microorganisms, and soil amendments used.

Phytoremediation is a form of bioremediation that utilizes plants to uptake harmful chemicals from the soil and groundwater. These harmful chemicals are then stored in the roots, stems or leaves of the plants where they are transformed into less harmful forms or released into the atmosphere. For instance, prairie grass can facilitate the breakdown of petroleum products (NCRS 200b). However, it is the microorganisms associated with the rhizosphere of plants (the root zone of plants) which are the primary agents of phytoremediation. Phytoremediation is typically suitable for moderately contaminated sites and often requires the removal of the plant material to eliminate contaminates from the site.

Bioremediation and phytoremediation are potential long-term strategies that can be integrated into a green infrastructure management plan. It is crucial to consult experts and follow the appropriate guidelines when implementing these strategies to ensure they are effectively employed to address the soil contamination specific to the urban area. It is advisable for project managers who intend to implement soil remediation as a preliminary step to green infrastructure or urban agriculture, to collaborate with State Brownfield, Voluntary Clean-Up Programs, or health agencies. These entities can provide technical information on addressing soil contamination.

CONCLUSIONS

Understanding urban soils and its potential or limitations helps in the evaluation of the urban site for green infrastructure and urban agriculture. Many urban soils will have a range of physical, chemical and biological limitations. These include insufficient organic matter, lack of biological activity, reduced water retention capacity, soil toxicity, and compaction. Despite this, urban soils have the potential to support plant growth and ecosystems.

Urban soils can vary greatly, even within the same site, and is influenced by the historical use of the site in addition to the geography and geology. Field studies and soil sampling are crucial to quantify the characteristics of the urban soil. Appropriate soil amendments can then be selected and properly applied to restore soil quality and reduce contamination thereby ensuring the success and long-term sustainability of the project and its benefits to the local communities.

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