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Addressing the Need for Soil Blends and Amendments for the Highly Modified Urban Landscape

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Applications of soil science will become increasingly important in urban ecosystems with anticipated population growth. Our overall objective was to address the issues involved in urban soil research. Specifically, the objectives were (i) to highlight past and current urban soil science research, (ii) to identity the need for special soil amendments and soil blends for urban landscape projects, and (iii) to encourage more soil scientists to address the research needs of rapidly expanding urban landscapes. Much of the early research with urban soils focused on identification and classification of anthropogenic influences. Those activities continue to be important, but there is an opportunity and need for soil scientists to expand their research activities into the area of highly modified and manufactured soils. Soil management in urban settings differs from natural and agricultural settings because the land units are smaller and the availability of soil amendments is much greater, thus the degree of modification is more intense. Organic and inorganic materials are abundantly used in urban landscapes as direct soil amendments or as ingredients in manufactured soils. These amendments can have a significant potential impact on soil and water resources in the urban environment. Soil scientists can make important contributions to urban soil science by developing good urban soil management practices, by evaluating the benefits and risks associated with soil amendments, and by developing soil blends for specialized urban applications such as parks, sports fields, plazas, and green roofs. The progression from a rural to an urban population effectively creates a variety of opportunities for soil scientists to conduct research, extension, and teaching activities with an ever-increasing urban focus.

Upon the 75th anniversary of the Soil Science Society of America, it is important to reflect on past accomplishments and to consider future directions for soils-related research and education activities. Our intent is to bring increased focus to the topic of urban soils. The development of new urban landscapes, as well as the revitalization and greening of existing cities, are worldwide trends that require the research and education participation of soil scientists. Cities are complex systems with multiple concerns besides soils, but more often than not, soil resources are not given adequate consideration by municipalities, developers, and other entities involved in urban landscape design and management. During the past 20 yr, soil scientists, especially in Europe (Burghardt, 1994; Lehmann and Stahr, 2007; Norra and Stüben, 2003; Rossiter, 2007) but also in North America (Craul, 1990; Effland and Pouyat, 1997; Howard and Olszewska, 2011) have begun focusing an increasing amount of attention on soil resources in urban landscapes. Much of the early work with urban soils was focused on soil taxonomy and classification. Soil scientists studied urban and industrial soils to develop classification systems and mapping techniques that would encompass them

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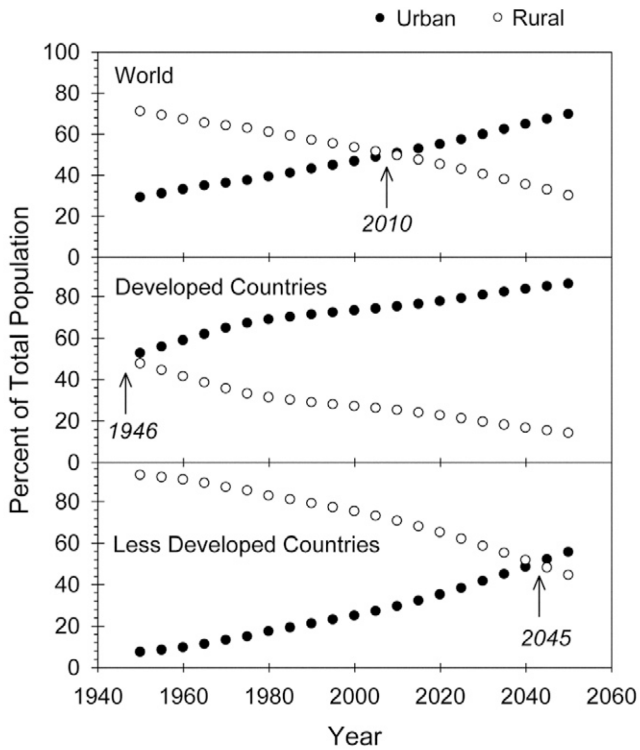


Fig. 1. Projections of the United Nations Development Program (UNDP) for rural and urban separation percentages of the world's population. The population data were obtained from the UNDP population database (United Nations Development Program, 2008).

within the soil taxonomic system (Hollis, 1991; IUSS Working Group WRB, 2006; Lehmann and Stahr, 2007; Norra et al., 2008; Rossiter, 2007). The large amount of field observations and laboratory analyses that accompanied these efforts resulted in significant increases in our knowledge of the nature and properties of urban soils. Collectively, these studies showed that urban soils had been impacted by a greater range of anthropogenic activities than most natural, agricultural, and forest soils.

Soil scientists have historically concentrated their research activities on soils in agricultural and natural areas because they produce most of the food and fiber needed by humans (De Kimpe and Morel, 2000). Although the knowledge gained through agricultural and environmental soil science research can be applied to urban situations, there is still a relatively small percentage of research studies with a specific focus on urban soils. World population trends suggest that there will be a growing incentive for soil scientists to focus on the use of soils resources in urban landscapes. Population projections from the United Nations Development Program (2008) predicted that the world population would become predominantly urban sometime around 2010 (Fig. 1). That point was reached in approximately 1948 in developed countries and will be reached in 2045 in the least developed countries of the world (United Nations Development Program, 2008). Given this reality, it is likely that a growing portion of the world's population will be interested in the sustainable use of soil resources in urban landscapes.

The term *urban soils* is rather broad and will have multiple meanings to different people (De Kimpe and Morel, 2000; Lehmann and Stahr, 2007). The International Union of Soil Science added the term *technosol* to their World Resource Base for Soils to describe a class of human-impacted soils that can be generally considered urban soils (Rossiter, 2007). We use the term *urban soils* to encompass the use of natural, modified, or manufactured growth substrates in urban and suburban landscapes that are highly influenced by human activities. Our objectives to address the issues involved in urban soil research are (i) to highlight past and current urban soil science research, (ii) to identity the need for special soil amendments and soil blends for urban landscape projects, and (iii) to encourage more soil scientists to address the research needs of rapidly expanding urban landscapes.

URBANIZATION EFFECTS ON SOIL CHEMICAL AND PHYSICAL PROPERTIES

The development of urban areas with the associated construction activities and various land uses results in significant modification of soil chemical and physical properties (Lehmann and Stahr, 2007; Norra and Stüben, 2003; Pouyat et al., 2007). Urban soil profiles frequently contain a variety of buried debris and artifacts, such as nails, bricks, glass, wood, plastics, cement, asphalt, paper, and organic waste materials (Craul, 1985, 1990; Howard and Olszewska, 2011). In addition, chemical contaminants such as pesticides, hydrocarbons, and heavy metals are commonly found in urban soils of the United States and other major cities of the world. Sources of contamination for urban soils include fossil fuel leaks or disposal, emissions from traffic and industry, and previous land uses, such as mining and smelting (Bridges, 1991; Thornton, 1991; Wang et al., 2008). Heavy metal concentrations in urban soils, especially Cd, Cu, Pb, and Zn, have been found to increase with population and traffic density (Bretzel and Calderisi, 2006; Chen et al., 2005; Madrid et al., 2002). Besides the direct toxicity of many metals in urban soils (Ebbs and Kochian, 1997; Jim, 1998), heavy metals can modify the biogeochemical cycling in urban soils by reducing the metabolism of soil microbes and microfauna, changing soil food webs, and reducing mineralization rates (Bååth, 1989; Pavao-Zuckerman and Coleman, 2007; Kuperman and Carreiro, 1997; Pouyat et al., 1994). Decomposition of waste materials frequently found at former commercial and industrial sites may also generate liquids and gases in the soil pores (Bridges, 1991). In an effort to address these types of degraded urban soils, the USEPA's Brownfields Program was started to promote and support the remediation and reutilization of blighted urban areas.

One of the most significant impacts of anthropogenic activities on urban soils is a change in the soil's physical functions. Urban soils often display a high degree of horizontal and vertical profile variability commensurate with the level of human disturbance. As a result of disturbance, the horizons of urban soils do not always run parallel to the soil surface, as observed in their natural or slightly modified counterparts (De Kimpe and Morel, 2000). Construction is probably the predominant human activity that leads to truncated soil development and the creation of discontinuous layers in the urban soil profile because it usually involves scraping, cutting, filling, and spreading of soil. Consequently, extreme differences in soil properties are common at small scales in the urban environment. In general, the transformation of natural soil into a disturbed and more heterogeneous body increases from the outskirts of a city to its center (Hall et al., 2009; Lemaire and Rossignol, 1999). Thus, urban renewal and greening projects, which are more common near city centers, are typically faced with degraded onsite soil conditions, and plans to modify or replace the onsite soil must be developed on a case-by-case basis.

Physical compaction resulting in increased bulk density is a widespread problem with urban soils (Mullins, 1991; Pouyat et al., 2007). Just as in agricultural soils, compaction destroys the natural structure of urban soils, resulting in reduced porosity with fewer or no macropores (Craul, 1990; Lemaire and Rossignol, 1999; Urban, 2008). Compaction also limits the movement of water through the soil profile, which can contribute to increased stormwater runoff (Pitt et al., 2008).

FERTILITY STATUS OF URBAN SOILS

Nutrient concentrations in soils in the urban landscape can vary widely due to the degree of past soil modifications and more recent management practices, especially the addition of fertilizers and other amendments (Lewis et al., 2006). In urban residential areas, lawn clippings are commonly returned to the soil by using mulching lawn mowers, but other landscape wastes are collected and disposed of as waste or transported to municipal or private composting facilities. It is becoming more common for large affluent municipalities with a strong tax base to offer yard waste collection services, with the waste being composted and returned to homeowners at little or no charge. At the same time that residents are mulching grass clippings and using compost, they continue to apply abundant amounts of soluble inorganic fertilizers that are readily and cheaply available in the garden centers of most "big-box" stores and supermarkets in North America.

Recent evidence shows that the trend in urban soils is toward increasing concentrations of nutrients, especially P (Struss et al., 2011). Pouyat et al. (2007) reported elevated Mehlich 1 extractable P and K concentrations in residential soils compared with unmanaged forest soils in the Baltimore, MD, area, but there were no differences in the total N concentrations. In a similar survey, the Texas AgriLife Extension Plant, Soil, and Water Testing Laboratory analyzed 1068 soil samples submitted by urban homeowners from 247 zip codes in Texas and found that 75% of the soil samples tested high (42–62 mg kg^{-1}) or extremely high (>62 mg kg^{-1}) in plant-available Mehlich 3 P (Table 1) (Mehlich, 1984). In contrast, only 10% of the samples had high concentrations of NO_3–N (Keeney and Nelson, 1982). Hall et al. (2009) found that urbanization of desert soils altered the native biogeochemical functions and resulted in elevated concentrations of soil organic matter and inorganic N. Although regional differences exist, the trend clearly indicates an anthropogenic increase in soil nutrient concentrations in urban areas.

Table 1. Soil P and N concentrations in 1068 urban soil samples collected in 2003 by homeowners from their landscapes in Texas. Soil samples were analyzed by the Texas AgriLife Extension Soil, Water, and Forage Testing Laboratory at College Station, TX, using standard procedures and protocol.

Sufficiency rating	Nutrient concentration	Samples (n = 1068)	Percentage of total
	mg kg^{-1}	no.	%
	Mehlich 3 plant-available P†		
Very low	<5	24	2.2
Low	6–10	43	4.0
Moderate	11–40	198	18.5
High	41–60	84	7.9
Very high	>62	719	67.3
	NO_3–N‡		
Low	<10	543	50.8
Moderate	10–30	416	39.0
High	>30	108	10.1

† Mehlich (1984).
‡ Keeney and Nelson (1982).

Due to excessive accumulation of nutrients in urban soils, some states in the United States are beginning to restrict the ability of residents to indiscriminately apply P, and in some cases N, fertilizers to areas with sensitive water bodies. In the state of Minnesota, the Phosphorus Lawn Fertilizer Law was enacted in 2002 and amended in 2004 (Minn. Stat., Ch. 18C, §60). The law seeks to prevent eutrophication of surface waters in "The Land of 10,000 Lakes" by regulating the use of P fertilizers on lawns and turf. A similar bill passed in 2011 in the state of Virginia (HB 1831) bans P from lawns starting in January 2013 to protect the highly impacted Chesapeake Bay. The Maryland Fertilizer Act, passed in 2011, includes restrictions for both N and P fertilizers including the type of fertilizer applied as well as the timing of application (Md. Agric. Code Ann., §§ 6-201, 6-222, 6-223, 6-224, 8-801, 8-803.4). In fact, 11 states currently have or are considering differing degrees of fertilizer bans at urban and state levels (Struss et al., 2011).

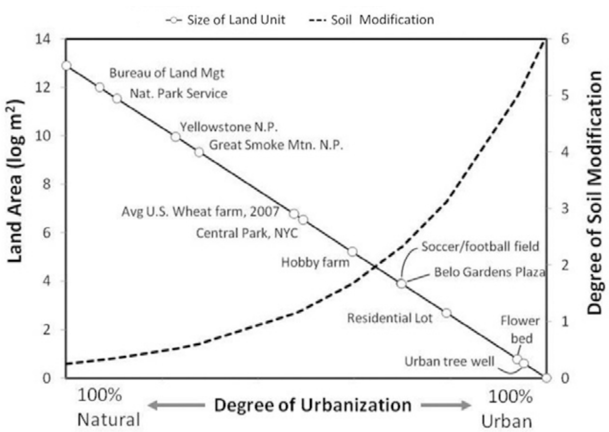
Differences in nutrient concentrations in urban soils suggest that prior soil fertility practices were not considered or taken into account for current nutrient management strategies. From an education perspective, there is a need to promote soil testing in urban landscapes and to educate the urban population on the selection of appropriate fertilizers and soil amendments. Perhaps the burden of soil testing on new landscapes should be placed on the landscape architects as a measure of their finished product and made available to the buyer of the property. Additional education materials, similar to the Urban Nutrient Management Handbook from the Virginia Polytechnic Institute and State University (Goatley and Hensler, 2011), are needed for each region that has its own unique soils-related management issues. From a research perspective, there is a need to study nutrient cycling in urban soils and to develop appropriate soil amendments and blends for unique urban situations (Lehmann and Stahr, 2007).

ORGANIC SOIL AMENDMENTS

The trend toward increased use of organic matter amendments in urban landscapes, consisting usually of some type of compost, complicates the issue of urban nutrient management. Compost is a source of organic matter that is readily available in urban landscapes due to municipal yard waste collection programs, beneficial biosolids utilization programs, and animal manure composting operations. Compost use has been thoroughly researched and its value as an urban soil amendment or as non-mineral growing media by the nursery industry has been described (Cogger, 2005; Hicklenton et al., 2001; Sæbø and Ferrini, 2006). There remain some important research needs related to compost use in urban settings, however, with regard both to its use as a direct soil amendment and also to its use in manufactured soils or growth substrates for unique urban development projects.

Information on the long-term effects of compost amendments on soil–water relations is limited. This aspect of compost use is important to municipalities seeking new ways to improve water use efficiency in urban landscapes. Compost is generally recognized as a beneficial amendment for increasing the water holding capacity of some coarse-textured and fine-textured soils (Curtis and Claasen, 2005, 2009; Weindorf et al., 2006). The heavy use of compost in urban landscapes, however, could lead to the development of hydrophobic soil properties due to the conversion of organic residues to progressively more hydrophobic forms during the composting process (Bartoli and Dousset, 2011; Said-Pullicino et al., 2007). Hydrophobic soil properties could lead to homeowners using extra water to rewet their soils after long periods of hot, dry conditions. Additionally, the effects of compost on soil properties are not always consistent and can vary with climatic conditions. Weindorf et al. (2006) reported that compost applied to silty clay and silty clay loam soils increased infiltration rates when antecedent rainfall was abundant but decreased infiltration following periods of scarce rainfall. They attributed the decreased infiltration rates to the conservation of antecedent soil moisture in plots amended with compost. Most studies on the use of compost have focused on the initial 2- to 3-yr period after application. Given the frequency with which compost is used in urban landscapes, combined with large application rates, more studies are needed to document the long-term and cumulative effects of compost in soils.

An increased use of compost in urban landscapes may also have an impact on stormwater runoff quality due to an accumulation of nutrients at or near the soil surface. In Texas, there is a clear indication of elevated biologically available P in the upper portions of urban soils (Table 1), and this could lead to increased concentrations of soluble P in runoff from urban landscapes. Glanville et al. (2004) reported that the use of 10-cm-thick compost blankets to control erosion on newly constructed highway embankments increased the time needed to generate runoff compared with embankment sections without the compost blanket but that once runoff began, the runoff water contained higher concentrations of dissolved and particulate P, Zn, and K. Johnson et al. (2006), on the other hand, demonstrated that by applying a 1-cm depth of dairy manure compost on turf, there were minimal effects on simulated rainfall runoff water quality but significant increases in plant-available P in the upper 10 cm of the soil. Hence, continued surface application of compost can potentially lead to increased soluble P in runoff from urban landscapes and will probably lead to an accumulation of nutrients at or near the soil surface. Runoff from urban landscapes is complicated by the ubiquitous presence of impervious surfaces (streets, alleys, parking lots, etc.) adjacent to landscapes where compost and other soil amendments are being applied to soils in abundant quantities. Runoff water that reaches these impervious surfaces is usually quickly conveyed through stormwater drainage systems to surface water bodies. Contaminated stormwater runoff can have serious implications for large urban populations, such as Dallas-Fort Worth, TX, that rely almost exclusively on surface reservoirs for their potable water supply or such as the Chesapeake Bay watershed that relies on the bay for a variety of human activities. Consequently, urban soil scientists have the opportunity and obligation to conduct research related to the effects of compost on the short- and long-term interactions among plants, soil quality, and stormwater runoff quality in the urban landscape.



	Description of Soil Modifications	
	Management Activity	Description / Examples
1	Vegetation control	brush control, controlled burns; mowing
2	Fertilizer and pesticide use	ammoniacal nitrogen, superphoshpate, potash
3	Soil tillage	plow, disk, rotary tiller, hoe, etc
4	Soil acidity adjustment	$CaCO_3$, $Ca(OH)_2$, elemental sulfur, etc.
5	Organic matter amendments	Manure, biosolids, compost, sphagnum peat moss
6	Mineral amendments	soil, sediment, sand, expanded shale, vermiculite, greensand, etc.

Fig. 2. Conceptual relationship between size of land unit and the degree of soil modification as land is converted from natural to urban, with a description of the corresponding soil modifications. For the purpose of this illustration, the soil modification practices are generally cumulative.

INORGANIC SOIL AMENDMENTS

Due to both real and perceived needs, and also the ease of availability, the use of various inorganic materials as soil amendments is much more prevalent in urban areas than in natural or agricultural areas (Fig. 2). In many instances, there is a real need for soil amendments to restore ecological function to degraded urban soils or to create soil blends to replace soils whose physical, chemical, or biological functions have been irreparably damaged by anthropogenic activities. Also, inorganic amendments are needed to create soil blends for specialized applications, such as green roofs and structural soils (Forschungsgesellschaft Landschaftsentwicklung Landschaftsbau, 1995; Grabosky and Bassuk, 1995). Conversely, the need for inorganic soil amendments is often based on perception rather than fact. For example, many urbanites in the Blackland Prairies region of Texas refer to the native soil (e.g., Houston Black clay, a fine, montmorillonitic, thermic, Udic Haplustert) as "black gumbo" and believe that it is unsuitable for gardening. While the soil can be challenging to work with due to its high clay content, it is, nevertheless, a naturally fertile soil with a high water holding capacity. The major soils-related concerns for Houston Black clay include potential water erosion, maintenance of soil organic matter and productivity, and management of soil moisture (NRCS, 2006). The perception of its greater shortcomings, however, has created a growing market for such products as expanded shale, lava sand, and green sand (glauconite). Inorganic mineral amendments such as these are common in the gardening centers of major stores, but there has been very little research to evaluate their effectiveness.

Research with expanded shale demonstrated some benefits for improving root growth and flowering, but the results were inconsistent across growing seasons and perhaps inconsequential given the cost of the product (Sloan et al., 2002). Conversely, expanded shale and slate are primary ingredients in specialized soil blends where there is a need for lightweight or highly porous media such as green roofs (Ampim et al., 2010; Beattie and Berghage, 2004; Rowe et al., 2006), stormwater control features (Sloan et al., 2008), and wastewater treatment wetlands (Forbes et al., 2004). Research related to the use of glauconite and lava sand as soil amendments is essentially absent from the scientific literature. Oftentimes, the use of a particular inorganic amendment is driven more by the availability of a local source rather than a response to a specific soils-based need. With the probable increase in the use of these inorganic soil amendments in urban landscapes, there is a need for soil science research to evaluate their effectiveness and their impact on soil and water resources in the urban landscape.

Zeolites are another class of inorganic minerals that have been investigated for use in specific soils-related applications, usually as a way to increase nutrient retention in sand-based golf course putting greens. Due to relatively high cation exchange capacities, 5 to 10% additions of clinoptilolite zeolites to sand can effectively increase the retention of NH_4–N (Ampim et al., 2009; Bigelow et al., 2001; Ferguson and Pepper, 1987; Huang and Petrovic, 1994) and K (Nus and Brauen, 1991) in the grass rooting zone. Some studies have also reported that addition of clinoptilolite zeolites to sand-based root zone mixes increased the water holding capacity (Ferguson and Pepper, 1987; Ok et al., 2003). Golf putting greens do not provide a good model for sustainable urban soils, however, because they are designed to drain rapidly while maintaining verdant growth. Consequently, they require frequent applications of water and fertilizer.

Comparatively fewer research efforts have been directed at evaluating the use of inorganic ingredients as beneficial amendments for contaminated or degraded urban soils or as ingredients in manufactured urban soils to immobilize heavy metals. Madrid et al. (2009) demonstrated that zeolites and slovakite (a synthetic, carbonate-rich material) can immobilize trace metals in contaminated urban soils. Sloan et al. (2008) reported that inclusion of natural clinoptilolite zeolites in an expanded shale based soil blend, designed to be used as a grass-covered parking surface, removed Cd and Pb from contaminated leachate but not Cu or Zn. Bruch et al. (2011) found that lava sands that contained zeolite minerals were effective at increasing the filtering efficiency of manufactured wetland soils, but those that did not contain zeolites were ineffective. Given the high degree of variability in the various inorganic mineral amendments available for use in urban landscapes, soil scientists can play an important role in evaluating the suitability of these materials for use as soil amendments and also in determining how to combine those inorganic materials with other ingredients to create unique and effective growing media for specific urban needs.

INTENSIFICATION OF SOIL MODIFICATION IN URBAN LANDSCAPES

The practice of making major modifications to the available soil resources or manufacturing soil blends is almost exclusively an urban phenomenon. In these situations, the basic principles of soil science, including the concept that soil inputs should improve or sustain soil quality and long-term productivity, are usually not a major consideration. The ability and feasibility of modifying soil resources changes considerably moving from natural areas to more highly developed urban areas. As illustrated in Fig. 2, the size of the land unit being managed can range from thousands of square kilometers in the case of the Bureau of Land Management and other federal agencies, to a few square meters in the case of urban parks, plazas, and homes. Inversely, the degree of soil modification is minor in large natural areas but becomes more prevalent for ranch and agricultural soils and reaches a high degree of modification in urban landscapes (Fig. 2). For example, the management of national forests periodically requires controlled burns to eliminate excessive vegetative debris, and fertilizers may be used to reestablish vegetation in burned or harvested areas, but any form of soil tillage or modification is mostly absent. Smaller land units, such as ranches, and especially farms, typically use some form of soil tillage in their soil management practices in addition to the use of fertilizers and pesticides. Smaller farms and organic farms typically include the use of some type of organic matter input, such as manures or composts. Soil tillage practices may also be more aggressive with smaller farms and include the use of implements, such as a rotary tiller, that significantly modify the soil condition more than a minimum form of soil tillage such as the chisel plow. As the unit of land being managed reaches the scale of the urban landscape, soil modification activities can become very intense. These activities can range from the addition of a variety of organic and inorganic ingredients to existing soils, such as in commercial properties and private residences, or in places where no native soil remains or it has been irreversibly degraded, to complete replacement of the existing soil with a manufactured soil.

MANUFACTURED SOILS

Manufactured soils can broadly be divided into two categories consisting of (i) topsoil mixes (also known as planting soils) or (ii) structural soils. The specifications for these soil blends are usually provided by the landscape architect company that designed the urban garden. These special soil blends are commonly created from non-local soil materials that are blended with manufactured or processed inorganic ingredients, such as sand or expanded shale. Ideally, they include a certain percentage of native soil salvaged on site or harvested from a nearby location. Manufactured soils are generally used where there is no on-site soil or the on-site soil is unsuitable for use due to physical or chemical contamination. In some cases, the on-site soil has to be significantly modified by mixing with various amendments to restore ecological functions and create a site-specific property, such as rapid infiltration and drainage. Drainage is a very important concern in urban landscapes due to the pervasiveness of impervious surfaces. In most urban situations, the existing onsite soils do not have the ability to drain at rates that help mitigate stormwater runoff, and therefore, organic and inorganic amendments are added to manufacture a soil with the desired property.

Topsoil mixes are usually made by mechanically blending a mineral base, such as subsoil or sand, with organic materials, such as compost or peat, and sometimes with the addition of lime and fertilizer (Carpenter and Fernandez, 2000). Blending can be accomplished in situ by tilling a 5- to 15-cm layer of organic matter into the existing soil, by mixing the ingredients in a tub mixer, or by folding together materials with front-end-load tractors (Cole, 1997). Another possible method for creating topsoil blends is to co-compost organic waste materials, such as municipal green waste, with inorganic materials such as coal fly ash (Belyaeva and Haynes, 2009) or other minerals such as zeolites or expanded shale. The use of compost technology, such as vessel composters, to co-process organic and inorganic waste materials while creating effective manufactured soils is another area of potential research for soil scientists.

The mineral components of topsoil mixes provide bulk and structure, while the organic materials provide nutrient and water retention and a substrate for microbial life (Cole, 1997). Composted wastewater biosolids have become a common ingredient in topsoil blends, such as AllGro, which has been used to revitalize soils in urban parks, sports fields, and golf courses (Cole, 1997). Other topsoil blends have been created by blending biosolids with inorganic byproducts, such as fly ash to create Ecoloam (Jarrett et al., 1994), or cement kiln dust to make N-Viro soil (Logan and Harrison, 1995). Public acceptance of biosolids products waxes and wanes with time, but the acceptance of composted vegetative waste, such as yard waste compost, is steadfast and growing due to the existence of municipal yard waste composting programs such as the Texas Pure program in Plano, TX. Master Composting and Master Gardener classes are also becoming popular and provide soil science educators with an opportunity to create educational materials and to teach the basic fundamentals of soil science to the general public.

Structural soils differ from topsoil mixes in that they are designed to provide an engineering function as well as support plant growth. They typically consist of a blend of mineral soil with a coarse aggregate (stone) and thereby form a highly porous (30–35%) matrix with a high load-bearing capacity and rapid infiltration rate that also allows root growth and development (Bartens et al., 2008, 2009). Thus, they are designed to provide structural support (i.e., load-bearing soils) beneath paved areas like sidewalks, streets, plazas, and parking lots while at the same time providing additional rooting space for trees beyond the traditional planting "pit" or "cutout" (Bartens et al., 2010). The structural component of these manufactured soils can consist of crushed stone, as in the Cornell University (CU) soil (Grabosky and Bassuk, 1998), or a light-weight heat-expanded shale or slate (Costello and Jones, 2003; Sloan et al., 2008). The CU soil is a mixture containing 80% (v/v) crushed granite or limestone rock and 20% clay loam soil (Grabosky and Bassuk, 1996). Another structural soil has been created by blending Carolina Stalite heat-expanded slate with a sandy clay soil at an 80:20 ratio (Bartens et al., 2009). Increased strength and permeability in structural soils are achieved at the cost of diminished water and nutrient holding capacity. Therefore, there is a research opportunity for soil scientists to further develop these special types of soil blends so that they have a greater capacity to supply water and nutrients to trees while maintaining a high degree of permeability and aeration.

A TYPICAL URBAN SOIL PROJECT

Construction of the Belo Garden in downtown Dallas, TX, is an example of an urban soil project that requires both topsoil and structural soil. For the past several decades, until 2010, the garden area was an asphalt parking lot near the Arts District. As part of an urban greening project, the former parking lot is being converted to a downtown pedestrian park including a combination of trees, shrubs, native grasses, and turf (Fig. 3). The soil underneath the paved lot was mostly unsuitable for reuse due to contamination and the presence of construction debris. Consequently, new soils were manufactured for this garden. Specifications for each of the new soils are shown in Table 2. The various areas within the garden where the three soil blends were used are shown in Fig. 3. The three blends included (i) a garden planting mix, (ii) a tree planting mix, and (iii) a load-bearing soil. Figure 4 is a cross-sectional view of how the load-bearing soil and garden planting mix will be used in tree vaults along the garden's streetscape.

In the case of the Belo Garden, the native soil used for the tree planting mix (Table 2) will be either Houston Black clay or Austin silty clay (a fine-silty, carbonitic, thermic Udorthentic Haplustoll) from the Blackland Prairies Resource Area in which

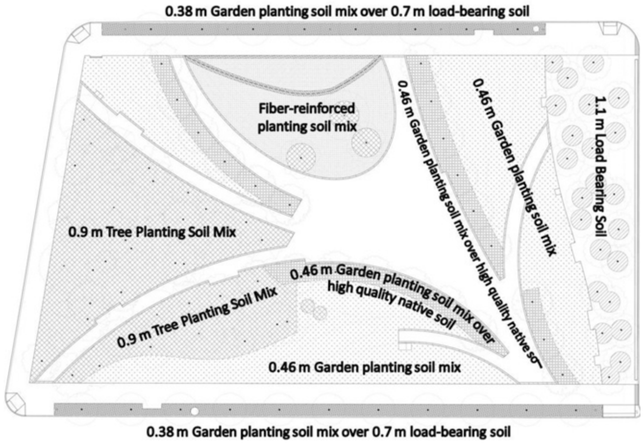


Fig. 3. Soil blends required for various planting areas within the Belo Garden in the City of Dallas, TX (graphic provided courtesy of Lara Rose, Hargreaves Associates, San Francisco, CA).

Table 2. Specifications for three soil blends needed for conversion of downtown parking lot into the Belo Garden pedestrian park (courtesy of Lara Rose, Hargreaves Associates, San Francisco, CA).

Soil mix	
Tree planting mix	
Upper layer (15 cm)	60% high-quality native topsoil (clay loam), 40% expanded shale; 8 cm of composted animal manure tilled into the top 15 cm (0.08 m^3 m^{-2})
Middle layer (30 cm)	high-quality native topsoil (clay loam)
Lower layer (45 cm)	high-quality native topsoil or subsoil
Garden planting mix	60% sandy loam soil, 25% aged (stable) vegetative composts, 15% animal manure compost
Load-bearing soil	40% sandy loam soil, 40% expanded shale, 10% zeolite minerals, 10% aged yard waste compost

the City of Dallas is located. Conversely, the garden planting mix and load-bearing soil both specify the use of a sandy loam soil, for which there is no local source, meaning that the soil will have to be harvested from another location and transported to the Dallas area. Other ingredients in the manufactured soils include highly processed materials—expanded shale and zeolites—and a local source of compost.

Upon completion of the Belo Garden project, which is typical of a high-value, inner-city greening project, the onsite soil resources will have been mostly imported from other locations. These types of urban greening and renewal projects are mostly designed and constructed by landscape architects who may or may not have training in soil science and who may or may not have consulted a soil scientist. Consequently, there is both opportunity and need for involvement from soil scientists for this type of urban greening and renewal project. Opportunities for soil scientists include remediation of on-site soils to minimize the costly importing of off-site materials and the design of soil blends that have appropriate physical, chemical, and biological properties to support urban vegetation while also attenuating stormwater runoff.

SUMMARY AND CONCLUSIONS

Due to an increasingly urban world population, the concept of urban soils should and will become a greater focus of research and education for soil scientists and other related disciplines. The groundwork for future urban soils research has already been laid by a relatively small group of soil scientists. Soil genesis and classification scientists have generated considerable information related to the wide range in soil physical and chemical properties due to anthropogenic activities and the effects they have on soil formation processes. Soil ecologists and chemists have identified many of the trends in soil properties due to urbanization processes. Moving forward from here will require soil scientists to become involved in a variety of urban greening projects that are becoming common in metropolitan areas. In particular, there is a need to apply the fundamentals of soil science to the development of substrates and structural soils for specialized purposes such as green roofs, stormwater infiltration areas, urban gardens, plazas, roadside revegetation, street medians, and many others. Research soil scientists accustomed to working in carefully designed field plot studies that are designed to minimize variability will find that research in the urban landscape can be more challenging due to

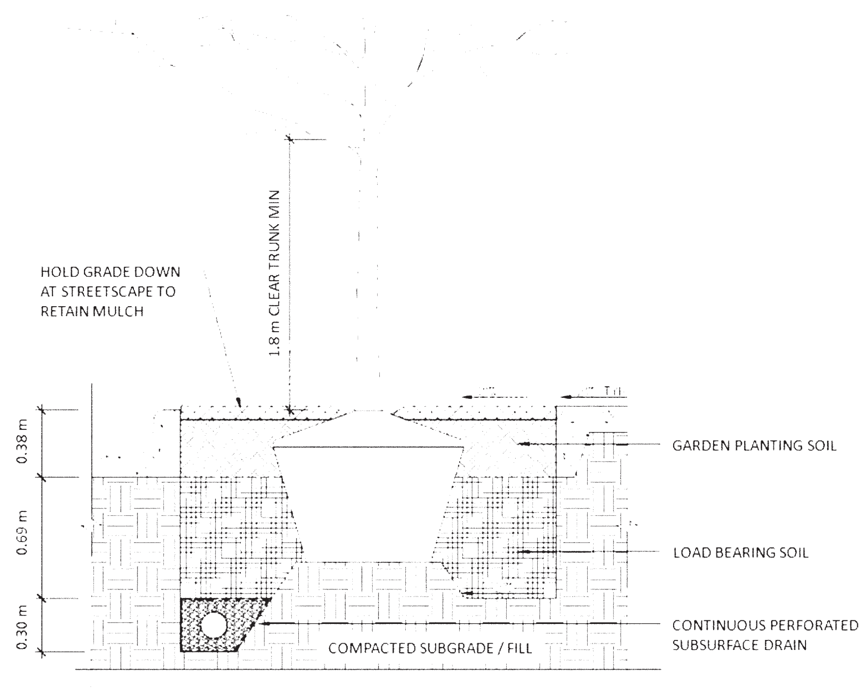


Fig. 4. Cross-sectional view of a tree well for the Belo Garden, showing the need for both a load-bearing soil and a garden planting soil (graphic provided courtesy of Lara Rose, Hargreaves Associates, San Francisco, CA).

such issues as spatial variability in the soils and the environment, limited space for research plots, unpredictable human and wildlife interruptions, and a general lack of control over experimental conditions. On the other hand, soil science educators will find that the growing urban population is very open and interested in learning to manage their urban soil resources in a way that will allow them to sustainably grow plants for a variety of purposes ranging from food to aesthetics.

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