by Julia Bartens, Nick Basta, Sally Brown, Craig Cogger, Bruce Dvorak, Britt Faucette, Peter Groffman, Ganga Hettairachchi, Kristen McIvor, Richard Pouyat, Gurpal Toor, and James Urban

Cities are often thought of as concrete jungles. Yet under all of the concrete exists a whole lot of soil—complex mixtures of minerals, water, air, and organic matter that perform many critical ecosystem functions. As our world becomes increasingly urbanized, the importance of studying these soils is coming to be recognized both from a purely scientific perspective and as a tool for sustainability in urban environments. SSSA is in the process of forming an Urban Soils Task Force, which will work to promote the study of urban soils within the Societies, provide education on soils for the range of constituents in urban areas, and integrate an understanding of soils into urban planning and infrastructure.

An appropriate understanding of soils plays a critical role in urban areas for a range of stakeholders including urban planners, urban residual management, and urban farmers. From a traditional soil science perspective, an understanding of ecosystem processes in urban areas is emerging as a field of study. This article highlights the role of soils in urban areas from this range of perspectives and is co-authored by a subset of the many members of SSSA who are studying varying aspects of soils in cities.

Soils and Anthropedology

Urban soils are generally thought of as disturbed, infertile, and having little systematic pattern in their spatial characteristics when compared with the native soils they replaced (Craul, 1992). However, more recent observations have shown that the response of soil to urban land-use change, while being complex and variable, does exhibit discernible patterns (e.g., Jenerette et al., 2006; Pouyat et al., 2007). Moreover, numerous studies have revealed a surprising level of biological activity in urban landscapes (e.g., Schleuss et al., 1998; Golubiewski, 2006).

Unfortunately, early observations of "urban soil" were considered by soil taxonomists to diverge from natural soil formation, and as a consequence, changes in soil characteristics resulting from urbanization have received limited attention in the current soil taxonomy (Fanning and Fanning 1989; Effland and Pouyat 1997; Evans et al., 2000). As a result, earlier definitions of urban soils reflected this bias. For example, Craul (1992) defined an urban soil as ". . .soil material having a non-agricultural, manmade surface layer more than 50 cm thick that has been produced by mixing, filling, or by contamination of land surface in urban and suburban areas."

Although the current soil taxonomy neglects soils altered by urban land use, it defines a soil as ". . . a collection of natural bodies on the earth's surface, in places modified or even made by man of earthy materials, containing living matter and supporting or capable of supporting plants out-of-doors" (Soil Survey Staff, 1975). In the spirit of this definition, progress has been made in developing a taxonomic system for disturbed soils (Lehmann and Stahr, 2007; Rossiter, 2007), while a definition of urban soil has been placed in a broader context of humanly altered soils, or "anthropogenic soils" (Evans et al., 2000; Dudal et al., 2002). Still others define urban soil to include not only those soils that are physically disturbed, but also those that are undisturbed yet altered by urban environmental change, e.g., temperature or moisture regimes (Pouyat and Effland 1999; Lehmann and Stahr, 2007).

However we define an urban soil, the definition must account for the observations made thus far; namely that like native soils, soil properties and their fauna can vary widely in urban landscapes, making it unrealistic to describe or classify a typical "urban" soil. What is more, urban soils exhibit a surprising capacity to support plant growth and soil fauna and thus are not necessarily infertile or have lower richness of species relative to the native soils they have replaced. Given these taxonomic and definitional insights and the important role they play in the provision of ecosystem services

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iStockphoto/ Steve Geer.

Trees provide critical functions in urban areas as integral components of ecosystem functions, as a natural alternative for stormwater regulation, and for improving urban aesthetics and livability. *Photo by John Cornicello.*

(where most of the human population lives), urban soils should be considered a research priority for the new field of anthropedology (as defined by Richter et al., 2011).

Helping a Tree Grow in Brooklyn

Most urban areas have significant amounts of open or green space. In some cases, these areas are already vegetated, some with remnant vegetation and others with deliberate plantings. These areas can be important as a means to understand how urban environments alter ecosystem processes and also have value for improving the quality of life in urban areas (Kuo and Sullivan 2001; Nowak et al., 2006; Bartens et al., 2008; Calder et al., 2008).

Ecological Processes in Urban Areas

Trees provide critical functions in urban areas as integral components of ecosystem functions, as a natural alternative for storm water regulation, and for improving urban aesthetics and livability. Concerns about the environmental impacts of urbanization have motivated the development of an understanding of basic soils processes in urban forests so that the environmental performance of urban soils and watersheds can be improved. Several studies of urban forest soils have taken advantage of urban to rural gradients (URGE; Carreiro and Tripler, 2005). The URGE approach was originally developed in and around New York City (Pouyat et al., 1995) and was quite effective for evaluating urban atmospheric effects on soil and ecosystem processes ranging from accumulation of heavy metals and base cations (Pouyat and McDonnell, 1991) to nitrogen deposition (Lovett et al., 2000) to phosphorus dynamics (Baxter et al., 2002) to soil–atmosphere fluxes of trace gases (Goldman et al., 1995). URGE gradients have also been useful for investigating biological changes in soils associated with chemical changes and enhanced potential for invasion of exotic species in urban areas (Baxter et al., 1999; Szlavecz et al., 2006).

In the National Science Foundation-funded urban long-term ecological research (LTER) project in Baltimore, a series of long-term forest study plots along an URGE were established that allow for comparison of urban atmospheric and inherent soil-type effects (Groffman et al., 2006). This network of plots also includes urban grasslands (lawns) and riparian areas that allow for evaluation of land use change and urban hydrologic change effects on soil processes. The work has focused on nitrogen cycling, with an eye towards preventing the movement of nitrate into the Chesapeake Bay (Groffman et al., 2002; Groffman et al., 2003) and on global warming potential associated with soil carbon storage (Raciti et al., 2011) and trace gas fluxes (Groffman and Pouyat, 2009; Groffman et al., 2009).

Trees for Livability

Street trees, trees planted on the border between sidewalks and streets, present a different challenge. Plants are typically included around buildings, parking lots, and in urban parks where the soils are highly disturbed by current or past construction. The average age of an urban tree has been measured at 10 years (Foster and Blaine, 1978). The shortened lifespans are likely due to planting trees in remnant undisturbed soil profiles, stockpiled and redistributed A and B horizon soils, or manufactured "topsoil" consisting of graded, mixed, and even heavily compacted B and C horizon soils. Standards for soil for tree plantings have traditionally been developed by landscape architects, civil engineers, or planners who typically do not recognize soil disturbance in the design of planting conditions or classic soil variables such as bulk density. In fact, engineering specifications often require that subsoil below planting areas be compacted to 90% of maximum density. Specifications for topsoil are vague and often not appropriate.

Educating landscape architects, civil engineers, and planners and making changes to current standards is challenging. Few site designers are well versed or even interested in learning about soils. Their skills must be improved in order for appropriate standards to be properly implemented, and they must be required to understand planting soil and estimate existing soil conditions even before the end of construction process, long before the last stages that include tree plantings.

Soil specifications must recognize, and treat separately, the different types of soil conditions and resources that may be encountered. Topsoil, soil chemistry, compaction, and compost specifications need to be rewritten. One of the most critical changes needed is to stop the aggressive screening and mixing of otherwise good soils. This processing of soil damages residual soil peds and dramatically reduces drainage. Understanding soils requires a more sophisticated approach than simply adding significant amounts of sand and compost to re-establish drainage. This practice alone can create a soil that is highly dependent on irrigation and fertilizer while being prone to settlement after compost decomposition.

Optimizing Soil for Survival

Street trees are often planted into rectangular or circular cutouts bordered by concrete. The vast majority of tree roots are contained in these pavement cutouts because surrounding soils are highly compacted for road and sidewalk construction. To assure that no roots escape, tree planting pits may even be lined with concrete. The available soil in these pavement cutouts is highly disturbed, too shallow (Jim, 1998a, 1998b), and contains residuals from surrounding construction such as stones, concrete, and other materials that may further decrease the volume of available soil and increase soil alkalinity with an associated decrease in micronutrient availability. Developing a rating system or index that categorizes a site for its potential to support a tree species' growth would help to efficiently categorize a site and facilitates the process of identifying a suitable species.

Street trees are often planted into rectangular or circular cutouts bordered by concrete. *Photo courtesy of localecology.org/Georgia Silvera Seamans.*

As opposed to identifying the right species for a given site, one can design a site to suit given species. Structural soils, also called engineered soils, can be a useful tool to increase the tree-available soil volume under the surrounding pavement by providing a substrate with a high load-bearing capacity to meet engineering standards that, due to its stone component, always provides a high porosity. Different structural soil mixes have been developed over the past 20 years such as CU Soil (Grabosky and Bassuk, 1995), Amsterdam Tree Soil, or structural soil with Carolina Stalite (Costello and Jones, 2003). In any case, a site needs to be suitable for a given species to grow large, healthy trees and to facilitate a sustainable urban forest that provides a high level of benefits.

Soils and Green Infrastructure

Urban planners and municipal officials are coming to recognize how integration of ecosystem services in an urban environment can both reduce energy usage and improve

Compost blanket installation. *Photo courtesy of San Jose Parks.*

quality of life (Center for Neighborhood Technology, 2010). Optimizing soil function in many cases is critical for success. Two examples illustrate this point: soil for stormwater bioretention systems and soils for green roofs.

Pervious Alternatives—Role of Soil for Restoring Hydrological Cycles

Soils in urban environments are compacted, eroded, and of low fertility, biology, and organic matter content. When combined with an ever-increasing impervious area, these land surfaces combine to increase stormwater volume and peak flow rates. This in turn increases pollutant loads, flooding, combined sewer overflows, and habitat destruction and ultimately reduces water quality. In recent years, low-impact development and green infrastructure programs have integrated natural design and management strategies to reduce site and watershed stormwater and its negative effects by rebuilding natural capital (organic matter, healthy soil, native vegetation, and biological diversity) and taking advantage of their free ecosystem services (stormwater and pollution reduction and water quality improvement and protection).

Improving soil infiltration and contaminant binding capacity has been critical in these efforts. Solutions to date have centered on the use of composts in stormwater bioretention systems. For example, compost blankets applied to urban soils have been shown to absorb more than 5 cm of rainfall in a 24-hour period (Faucette et al., 2005; Faucette et al., 2007). Absorbing and detaining high volumes of rainfall at the ground surface allows for higher rates of infiltration, surface evaporation, and plant-available water, thereby helping to re-establish pre-development hydrologic patterns. These high absorption rates, combined with the rough surface areas characteristic of the composts used in these applications, delay the onset of runoff and peak flow conditions under high intensity and duration storm events (Faucette et al., 2005; Faucette et al., 2007).

Professional designers suggest that the compost blankets look and act like a forest floor, or duff layer, which historically existed prior to development or current land use. These reports may in fact have validity. Stormwater design values for vegetated compost blankets show that runoff curve numbers and runoff coefficients attributed to vegetated compost blankets are similar to natural forest and pasture conditions.

Up on the Roof

Rooftop gardens have a long history reaching back to the Ziggurats of ancient Mesopotamia and the fabled Hanging Gardens of Babylon. Today, roof gardens are found in urban centers around the world as roof deck plazas such as Millennium Park in Chicago, healing gardens in hospitals, or organic rooftop vegetable farms in New York City. Extensive green roofs also have a long history reaching back to Scandinavian settlements since the Middle Ages or earlier. These sod-covered structures helped insulate interior living spaces for those living in frigid climates of northern Europe long before electricity and modern heating systems were developed.

Research on appropriate soils for these roofs was pioneered by German scientists. In the 1970s, a group of researchers developed the FLL German Guidelines for Rooftop Greening, which aided those developing, designing, and constructing vegetated roofs. Critical features for green roof soils were defined including growing medium compo-

Left: Chicago City Hall green roof. *Photo courtesy of Wikipedia/ Tony the Tiger*. **Bottom:** Ed McLean, a landscape supervisor with Appalachian State University's Physical Plant, weeds the green roof on the W. Kerr Scott Hall. *Photo by Marie Freeman.*

sition, fertility requirements, and drainage characteristics. During the 1980s, major advancements in development of lightweight growing mediums have allowed green roofs to become part of standard building construction worldwide. Today, the FLL guidelines represent the state-of-the-art performance specifications for green roofs in Europe and abroad.

Green roof technology in the United States is still emerging. The composition of the media is critical in determining the effectiveness of the green roof to improve urban ecology. Research in the Pacific Northwest and the East Coast demonstrated how media can be a source of stormwater nutrient loading if too much fertilizer is applied or if animal waste is used as a source of organic compost. Regional differences are also critical in developing an appropriate soil. Researchers at Penn State found that green roofs produced according to FLL guidelines hold on to too much water during wet periods and thus reduce the performance of plants and the retention capacity of the green roof.

Despite some of the disparity of research findings, there are many agreements. Green roofs are very effective in reducing urban flooding; they capture carbon and clean the air, reduce energy use, and help manage urban heat islands. They have been found to be islands of habitat for urban wildlife and can produce food where the land perhaps only long ago supported such activity. Green roof technology is still under development in the United States; however, research and innovation continues to expand the possibilities and benefits of urban greening with green roofs.

Grow Local

Urban agriculture is experiencing a resurgence not seen since the Victory Gardens of the Second World War; however, there are many impediments to success. Most gardeners have little to no experience with growing any type of food. In many cases, urban soils are low in nutrients and have poor physical properties, making it difficult to grow a crop. Finally, urban soils can be contaminated, causing concern on the safety of consuming crops grown in these soils. Working to make these urban gardeners successful in their efforts requires education efforts, development of methods to improve soils, and evaluation of contaminant bioavailability to assure that gardening is safe.

Bottom: Urban agriculture is experiencing a resurgence not seen since the Victory Gardens of the Second World War. *Photo courtesy of the Vermont Valley Community Farm (http://vermontvalley.com/home.htm).* **Right:** Urban soil can be contaminated, and children can be exposed to the contaminants via direct consumption. *Photo courtesy of Bismarck Parks and Recreation District.*

Benefit or Hazard?

Increased food prices coupled with a greater awareness among consumers to be cognizant of their food supply has created an incentive for urban-based, non-profit organizations and neighborhood groups to initiate the establishment of vegetable gardens around various city centers across the country. Growing vegetables in an older urban environment can present challenges because of the possibility of soil contamination. Lack of understanding about soil contamination continues to be a cause of concern for urban gardeners and associated community groups. Three common contaminants in urban areas include (1) lead from the use of once-legal lead paint and gasoline, (2) arsenic from arsenic-containing wood preservatives and pesticides, and (3) polyaromatic hydrocarbons—a by-product of burning materials such as coal, wood, and oil. Research on these urban soil contaminants shows that they are strongly fixed (adsorbed) to soil particles and hence are not readily taken up by plants. As a result, their concentrations in the above-ground portions of the common vegetables grown in urban gardens are very low.

However, high concentrations of these contaminants are often detected in soils. This means that children can be exposed to them by direct consumption of soil. It is well known that the total concentration of these contaminants in the soils is not strongly related to their bioavailability or potential toxicity (Ryan et al., 2004). Bioavailability of these contaminants is generally low in soils, especially if the contamination had occurred in the past and contaminants had time to "age" or sequester in soils. Further, if a site is tested as high in lead, arsenic, or polyaromatic hydrocarbons, contaminant bioavailability can be reduced by suitable soil amendments (including composts produced from local organic residuals and phosphorus fertilizers) capable of binding contaminants, which can also improve soil quality. A recent need assessment survey, conducted in Tacoma/Seattle, WA, and Kansas City, KS/MO, generated information about what urban gardeners and farmers know and want to know about urban soil quality and contamination. Survey results suggest that urban gardeners and farmers need and want information and guidance on (1) soil testing for com-

Washington State University Master Gardener volunteers in Grays Harbor and Pacific Counties.

mon contaminants, (2) interpretation of testing results, and (3) best management practices for growing food on mildly contaminated urban soils. Soil testing is needed to screen soils for contaminants. USEPA Phase I and II investigations, commonly used for Brownfields sites, cost tens of thousands of dollars and screen for a large array of potential contaminants, and because of this excessive cost, most gardeners do not test their soil for contaminants. A simpler and inexpensive soil-screening protocol could help to realize wide-scale soil testing of urban soils used for food production.

Texture Triangle

Your typical urban dweller probably isn't an expert on soils. They may have a hard time identifying the type of soils prevalent in their areas or explaining the difference between sand, silt, and clay. But the recent increase in interest among many in growing their own food has provided a window of opportunity for those who care about soils to connect with urban residents who are now willing to learn. Community gardening and other forms of urban agriculture are providing a diverse array of opportunities for urban residents to get to know the soils in their areas as well as how to use local resources to care for them so that both the soil and the people who are using them to grow food are healthier in the future.

In Tacoma, WA, a wide range of soil educators are teaching new gardeners. In some cases, individual gardens have developed their own education programs. For example, at the Franklin Community Garden in Tacoma, experienced gardeners teach newer ones about soils and composting. A composting area has been reclaimed from a previously unused portion of the garden, and work parties are planned to construct a number of different types of composting structures. A local organization, Hilltop Urban Gardens, has developed programming for the nearby chapter of the Boys and Girls club to provide education in the garden. Titled the Garden Justice Club, youth participate biweekly in hands-on garden-based learning. Through partnerships with local soil scientists at Washington State University Extension, the youth have done soil testing and learned how important it is to take care of the soil. They are also now experienced at vermicomposting and compost their food scraps. Another local organization, the Guadalupe Land Trust, has recently completed the construction of a new type of garden for the community—a learning garden. This year, they will be launching a Garden Steward Program to involve local community members in the design and care of the garden as well as in providing educational programming. Finally, in gardens where all participants are novices, the gardens are partnering up with the Washington State University Extension Master Gardener program. Master Gardeners act as mentors to the new garden group—answering questions, providing workshops, and connecting new gardeners to other experienced gardeners throughout the city.

Waste to Resource

Gardeners in Tacoma have a greater chance of success due to the availability of locally produced soil amendments. Recycling urban organic wastes to supply nutrients and improve soils in city yards and gardens is a decades-long tradition in this city. Tacoma developed its soil amendment tradition with biosolids recycling programs in the 1950s, which led to the production of Class A Tagro biosolids products beginning in 1991. Through local demonstration gardens, participation in Master Gardener and community garden programs, research partnerships with local universities, and word of mouth, Tagro products have become a source of pride among Tacoma gardeners, with the 6,000 Mg annual production selling out every year.

Long-term research plots (7 to 15 years) set up by Washington State University indicate that organic matter additions from Tagro and compost increase soil organic matter, with the increase equivalent to nearly 25% of the initial organic carbon additions, leading to a potential of 1,500 Mg of C sequestered each year in the Tacoma area (Brown et al., 2012). The City of Tacoma also worked with WSU to develop a potting soil mixture using the Class A biosolids. Tacoma has been successful at connecting urban waste recycling with urban soil quality, encouraging its residents to create healthy gardens and landscapes and restore urban soils.

Conclusions

This review has highlighted just a portion of the ways that soil science plays a role in urban areas. In many cases, urban managers and city dwellers have recognized the importance of soils and are looking for information—not realizing the resources that are already available. Simultaneously, soil scientists have traditionally not considered that their knowledge can have value in an urban environment. One of the primary goals of the Urban Soils Task Force will be to create bridges between these groups. Another is to share basic knowledge for the range of city dwellers who are just becoming aware of the world below their feet.

References

Bartens, J., S.D. Day, J.R. Harris, J.E. Dove, and T.M. Wynn. 2008. Can urban tree roots improve infiltration through compacted subsoils for stormwater management? J. Environ. Qual. 37:2048–2057.

Baxter, J., S.T.A. Pickett, M.M. Carreiro, and J. Dighton. 1999. Ectomycorrhizal diversity and community structure in oak forest stands exposed to contrasting anthropogenic impacts. Can. J. Bot. 77:771–782.

Baxter, J.W., S.T.A. Pickett, J. Dighton, and M.M. Carreiro. 2002. Nitrogen and phosphorus availability in oak forest stands exposed to contrasting anthropogenic impacts. Soil Biol. Biochem. 34:623–633.

Brown, S., C. Cogger, and E. Miltner. 2012. Soil carbon sequestration potential in urban areas. p. 173–196. *In* R. Lal and B. Augustin (ed.) Carbon Sequestration in Urban Ecosystems. Springer, Berlin.

Calder, I., J. Harrison, T. Nisbet, and R. Smithers. 2008. Woodland actions for biodiversity and their role in water management. Available at http://eprint.ncl.ac.uk/pub_details2.aspx?pub_id=54851 (verified 29 June 2012).

Carreiro, M.M., and C.E. Tripler .2005. Forest remnants along urban–rural gradients: Examining their potential for global change research. Ecosystems 8:568–582.

Center for Neighborhood Technologies. 2010. The value of green infrastructure: a guide to recognizing its economic, environmental and social benefits. Available at http://www.cnt.org/repository/gi-values-guide.pdf (verified 26 June 2012).

Costello, L.R., and K.S. Jones. 2003. Reducing infrastructure damage by tree roots: a compendium of strategies. Western Chapter of the International Society of Arboriculture, Porterville, CA.

Craul, P.J. 1992. Urban soil in landscape design. John Wiley & Sons, Inc., New York.

Dudal, R., F. Nachtergaiel, and M.F. Purnell. 2002. The human factor of soil formation. Paper. 93. *In* World Congr. of Soil Sci., 17th, Bangkok, Thailand. 14–21 Aug. 2002.

Effland, W.R., and R.V. Pouyat. 1997. The genesis, classification, and mapping of soils in urban areas. Urban Ecosyst. 1:217–228.

Evans, C.V., D.S. Fanning, and J.R. Short. 2000 Human-influenced soils. p. 33–67. *In* R.B. Brown, J.L. Anderson, and J.H. Huddleston (ed.) Managing Soils in a Growing Urban Area. Agron. Monogr. 39. ASA, Madison, WI.

Fanning, D.S., and M.C.B Fanning. 1989. Soil morphology, genesis, and classification. John Wiley, New York.

Faucette, L.B., C.F. Jordan, L.M. Risse, M. Cabrera, D.C. Coleman, and L.T. West. 2005. Evaluation of storm water from compost and conventional erosion control practices in construction activities. J. Soil Water Conserv. 60(6):288–297.

Faucette, L.B., J. Governo, C.F. Jordan, B.G Lockaby, H.F. Carino, and R. Governo. 2007. Erosion control and storm water quality from straw with pam, mulch, and compost blankets of varying particle sizes. J. Soil Water Conserv. 62(6):404–413.

Foster, R.S., and J. Blaine. 1978. Urban tree survival: trees in the sidewalk. J. Arboric. 4:14–17.

Goldman, M.B., P.M. Groffman, R.V. Pouyat, M.J. McDonnell, and S.T.A. Pickett. 1995. CH_4 uptake and N availability in forest soils along an urban to rural gradient. Soil Biol. Biochem. 27:281–286.

Golubiewski, N.E. 2006. Urbanization increases grassland carbon pools: Effects of landscaping in Colorado's front range. Ecol. Appl. 16:555–571.

Grabosky, J., and N. Bassuk. 1995. A new urban tree soil to safely increase rooting volumes under sidewalks. J. Arboric. 21:187–201.

Groffman, P.M., and R.V. Pouyat. 2009. Methane uptake in urban forests and lawns. Environ. Sci. Technol. 43:5229–5235.

Groffman, P.M., C.O. Williams, R.V. Pouyat, L.E. Band, and I. Yesilonis. 2009. Nitrate leaching and nitrous oxide flux in urban forests and grasslands. J. Environ. Qual. 38:1848–1860.

Groffman, P.M., N.J. Boulware, W.C. Zipperer, R.V. Pouyat, L.E. Band, and M.F. Colosimo. 2002. Soil nitrogen cycle processes in urban riparian zones. Environ. Sci. Technol. 36:4547–4552.

Groffman, P.M., R.V. Pouyat, M.L. Cadenasso, W.C. Zipperer, K. Szlavecz, I.D. Yesilonis, L.E. Band, and G.S. Brush. 2006. Land use context and natural soil controls on plant community composition and soil nitrogen and carbon dynamics in urban and rural forests. For. Ecol. Manage. 236:177–192.

Groffman, P.M., D.J. Bain, L.E. Band, K.T. Belt, G.S. Brush, J.M. Grove, R.V. Pouyat, I.C. Yesilonis, and W.C. Zipperer. 2003. Down by the riverside: urban riparian ecology. Front. Ecol. Environ. 1:315–321.

Jenerette, G.D., J. Wu, N.B. Grimm, and D. Hope. 2006. Points, patches, and regions: scaling soil biogeochemical patterns in an urbanized arid ecosystem. Global Change Biol. 12:1532–1544.

Jim, C. 1998a. Physical and chemical properties of a Hong Kong roadside soil in relation to urban tree growth. Urban Ecosyst. 2:171–181.

Jim, C. 1998b. Urban soil characteristics and limitations for landscape planting in Hong Kong. Landscape and Urban Planning 40:235–249.

Kuo, F.E., and W.C. Sullivan. 2001. Environment and crime in the inner city. Environ. Behav. 33:343–367.

Lehmann, A., and K. Stahr. 2007. Nature and significance of anthropogenic urban soils. J. Soils Sediments 7:247–260.

Lovett, G.M., M.M. Traynor, R.V. Pouyat, M.M. Carreiro, W.X. Zhu, and J.W. Baxter. 2000. Atmospheric deposition to oak forests along an urban-rural gradient. Environ. Sci. Technol. 34:4294–4300.

Nowak, D.J., D.E. Crane, and J.C. Stevens. 2006. Air pollution removal by urban trees and shrubs in the United States. Urban Forestry & Urban Greening 4:115–123.

Pouyat, R.V., and M.J. McDonnell. 1991. Heavy metal accumulations in forest soils along an urban-rural gradient in southeastern New York, USA. Water Air Soil Pollut. 57-58:797–807.

Pouyat, R.V., M.J. McDonnell, and S.T.A Pickett. 1995. Soil characteristics of oak stands along an urban-rural land use gradient. J. Environ. Qual. 24:516–526.

Pouyat, R.V., and W.R. Effland. 1999. The investigation and classification of humanly modified soils in the Baltimore Ecosystem Study. *In* J.M. Kimble, R.J. Ahrens, and R.B. Bryant (ed.) Classification, correlation, and management of anthropogenic soils. Proc. Nevada and California, 21 September–2 October 1998. USDA-NRCS National Survey Center, Lincoln, NE.

Pouyat, R.V., I.D. Yesilonis, J. Russell-Anelli, and N.K. Neerchal. 2007. Soil chemical and physical properties that differentiate urban land-use and cover types. Soil Sci. Soc. Am. J. 71:1010–1019.

Raciti, S.R., P.M. Groffman, J.C. Jenkins, R.V. Pouyat, T.J. Fahey, M.L. Cadenasso, and S.T.A. Pickett. 2011. Accumulation of carbon and nitrogen in residential soils with different land use histories. Ecosystems 14:287–297.

Richter, D. deB., A.R. Bacon, L.M. Megan, C.J. Richardson, S.S. Andrews, L. West et al. 2011. Human–soil relations are changing rapidly: Proposals from SSSA's Cross-Divisional Soil Change Working Group. Soil Sci. Soc. Am. J. 75:2079–2084.

Rossiter, D.G. 2007. Classification of urban and industrial soils in the world reference base for soil resources. J. Soils Sediments 7:96–100.

Schleuss, U., Q.L. Wu, and H.P. Blume. 1998. Variability of soils in urban and periurban areas in Northern Germany. Catena 33:255–270.

Ryan, J.A., W.R. Berti, S.L. Brown, S.W. Casteel, R.L. Chaney, M. Doolan, P. Grevatt, J. Hallfrisch, M. Maddaloni, D. Moseby, and K. Scheckel. 2004. Reducing children's risk to soil lead: summary of a field experiment. J. Environ. Sci. Technol. 38:19a–24a.

Soil Survey Staff. 1975. Soil taxonomy—a basic system of soil classification for making and interpreting soil surveys. USDA Soil Conservation Service, Washington, DC.

Szlavecz, K., S.A. Placella, R.V. Pouyat, P.M. Groffman, C. Csuzdi, and I. Yesilonis. 2006. Invasive earthworm species and nitrogen cycling in remnant forest patches. Appl. Soil Ecol. 32:54–62.

J. Bartens, University California–Davis; N. Basta, Ohio State University; S. Brown, University of Washington; C. Cogger, Washington State University; B. Dvorak, Texas A&M University; B. Faucette, Forester University; P. Groffman, Carey Institute for Ecosystem Studies; G. Hettairachchi, Kansas State University; K. McIvor, Forterra; R. Pouyat, U.S. Forest Service; G. Toor, University of Florida; and J. Urban, FASLA