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SPECIAL SECTION

SOIL IN THE CITY

Soil in the City: Sustainably Improving Urban Soils

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Abstract

Large tracts of abandoned urban land, resulting from the deindustrialization of metropolitan areas, are generating a renewed interest among city planners and community organizations envisioning the productive use of this land not only to produce fresh food but to effectively manage stormwater and mitigate the impact of urban heat islands. Healthy and productive soils are paramount to meet these objectives. However, these urban lands are often severely degraded due to anthropogenic activities and are generally contaminated with priority pollutants, especially heavy metals and polycyclic aromatic hydrocarbons. Characterizing these degraded and contaminated soils and making them productive again to restore the required ecosystem services was the theme of the "Soil in the City— 2014" conference organized by W-2170 Committee (USDA's Sponsored Multi-State Research Project: Soil-Based Use of Residuals, Wastewater, & Reclaimed Water). This special section of *Journal of Environmental Quality* comprises 12 targeted papers authored by conference participants to make available much needed information about the characteristics of urban soils. Innovative ways to mitigate the risks from pollutants and to improve the soil quality using local resources are discussed. Such practices include the use of composts and biosolids to grow healthy foods, reclaim brownfields, manage stormwater, and improve the overall ecosystem functioning of urban soils. These papers provide a needed resource for educating policymakers, practitioners, and the general public about using locally available resources to restore fertility, productivity, and ecosystem functioning of degraded urban land to revitalize metropolitan areas for improving the overall quality of life for a large segment of a rapidly growing urban population.

Core Ideas

- Urban soils are contaminated by priority pollutants due to anthropogenic activities.
- Urban soils quality can be improved by using local resources such as composts and biosolids.
- Improving soils is key to improving the overall ecosystem functioning in urban areas.
- These papers are a resource for policymakers, practitioners, and the general public.

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Deindustrialization of metropolitan areas has resulted in large tracts of abandoned urban land. Renewed interest among city planners and community organizers has arisen to use this land productively for multiple purposes. Examples include, but are not limited to, growing plants for fresh food (urban farming), stormwater management, and mitigation of the urban heat island effect. There are several additional advantages and opportunities to improve the environment and ecology of cities by improving microclimate, restoring urban soils to provide ecosystem services, maximizing beneficial utilization of the waste generated in the cities, improving stormwater management, and enhancing biodiversity.

Furthermore, locavorism—the focus on eating locally grown foods—is gaining popularity in the United States and worldwide. This idea, however, seems counterintuitive to most people living in the urban setting who considered farming as an exclusively rural endeavor. Many countries in the world have already adopted urban agriculture as a result of the explosion of the urban population, especially in many Asian cities, mainly due to economic and political changes that have undermined the food distribution systems (Brown and Jameton, 2000). In addition to the value of urban agriculture leading to improved nutritional health, local economy, and food security in the United States, the value of green spaces in the urban setting is also being recognized by policymakers, health professionals, urban planners, environmental advocates, and the local community for improved personal wellness, environmental health benefits, and community betterment.

The renewed interest in urban farming in many metropolitan cities across the United States has resulted in greater attention to improving the quality of urban soils. Understanding the problems inherent to degraded urban soils is essential for bringing more urban soils into productive use for improving the quality of life for a large segment of a rapidly growing urban population.

Urban regions are centers of resource consumption and waste production, where raw materials are consumed directly or transformed into other products that either become part of the urban infrastructure or are discarded through one of many waste streams leaving urban regions for disposal. Material flows (e.g., food, raw materials, and water) in and out of metropolitan

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Abbreviations: GI, green infrastructure; PSI, P saturation index; WWTP, wastewater treatment plant.

regions, and transformation processes within, are complex pathways and are generally managed by different city agencies in isolation. As major metropolitan regions have adopted urban sustainability programs and policies, there has been an increasing awareness among city planners and local governmental agencies to the importance of addressing the sustainability linkages among these different resource domains simultaneously for more efficient resource use and recovery, as depicted in Fig. 1 (Brose et al., 2014). Recovered resources, such as municipal solid waste compost, biosolids, and harvested nutrients from wastewater, are available in urban areas and could be utilized for improving the fertility and ecosystem function of urban soils. Household composting and municipal-level solid waste composting are notable examples, where city waste is diverted from landfills and turned into compost, which is then used to amend soil to improve productivity as well as other ecosystem services. Another example is the supply of nutrients brought in the form of food to the cities not only from neighboring rural areas but also from around the world. A significant proportion of these nutrients are released in human feces and urine and sent to wastewater treatment plants (WWTPs) (Brose et al., 2014).

The main objective of the Soil in The City conference organized by the W-2170 Committee (USDA's Sponsored Multi-State Research Project Soil-Based Use of Residuals, Wastewater, & Reclaimed Water) was to educate practitioners and the general public on how to mitigate the risks from priority pollutants often found in urban soils and to reclaim and improve urban soils using local resources to grow health food and provide stormwater management benefits. This special section of *Journal of Environmental Quality* comprises 12 targeted papers authored by conference participants to make available much needed information about the characteristics of urban soils.

Soil Quality Assessment in Urban Areas

Contamination of urban soils by trace metals is a major concern because of the risk these elements pose to the environment and to human health. Due to the long residence time of heavy metals in soils, urban soils may act as both a sink and a source for these pollutants. Many of these trace metals may be present in parent material from where soils have developed and may be inherently high in some of these metals; however, in many cities, anthropogenic activities have resulted in the substantial contamination of urban soils (Mielke et al., 1983; Mitchell et al., 2014). The study conducted by Delbecque and Verdoodt (2016) shows that the concentration of trace metals in an urban environment was highly variable due to both diffuse and point sources of these contaminants. The main objective of the study was to reveal spatial patterns of anthropogenic heavy metal enrichment using an urban pollution index in the medium-sized city of Ghent, Belgium. The study focuses on eight heavy metals (As, Cd, Cr, Cu, Hg, Ni, Pb, and Zn), and the urban pollution index was developed based on a database of 2194 observations. The relationship, if any, between enrichment of these metals with land use and time since urbanization is also evaluated.

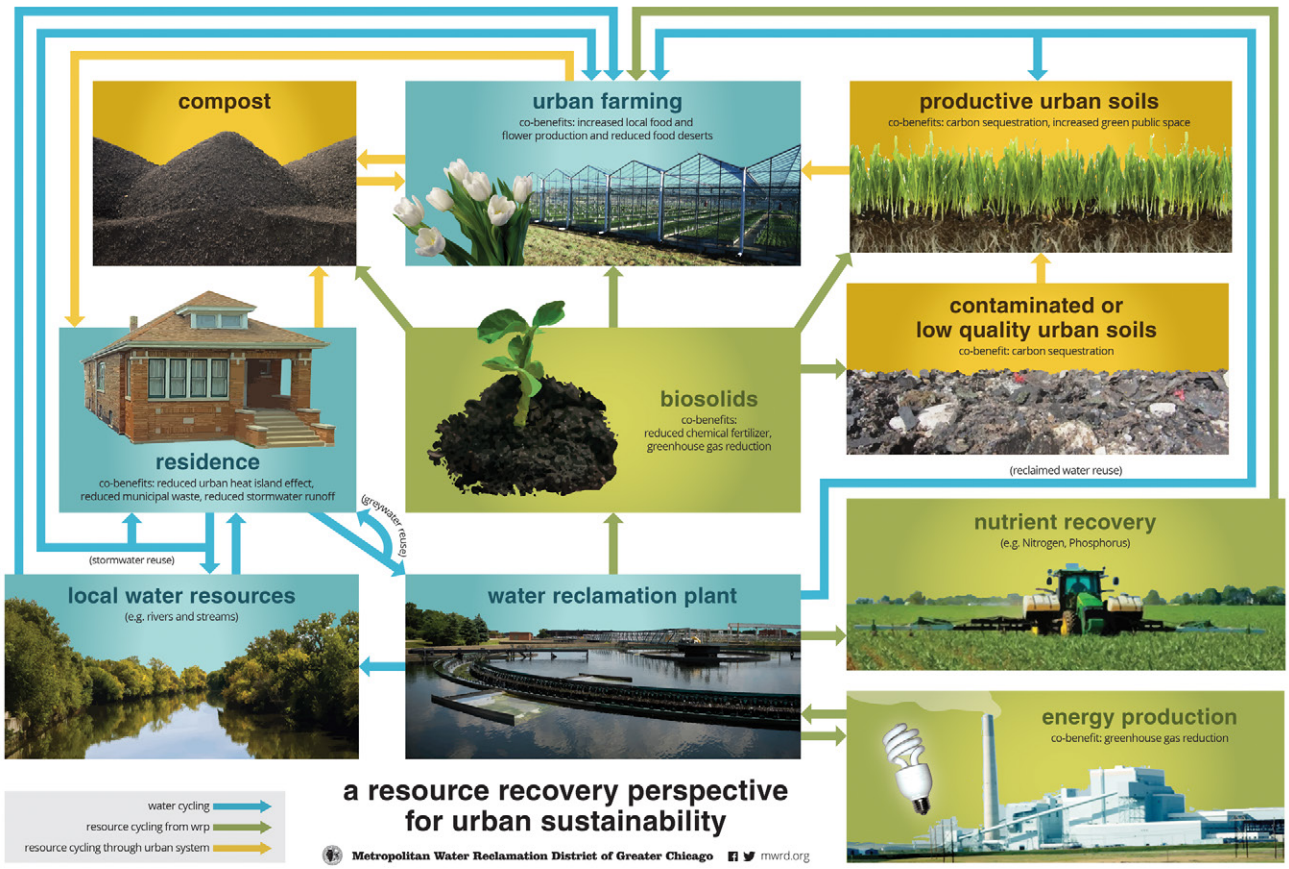

Fig. 1. A resource recovery perspective for urban sustainability.

Montgomery et al. (2016) present the results of a preliminary study conducted by a team of undergraduate students and community members to assess the soil quality of four abandoned residential lots located on the south side of Chicago with the aim of evaluating these vacant lots for appropriate land use, such as rain gardens, vegetable gardens, or playlots for children. All abandoned lots evaluated in this study exhibited the typical characteristics of an urban area in an industrial city and were littered with demolition debris, including glass, metal, bricks, concrete rubble, and other anthropogenic refuse. Results shows the soil quality in these lots was low, total lead concentrations were high with three out of four lots showing total lead concentrations exceeding the USEPA's threshold limit of 400 mg kg^{-1} for children's bare soil play areas, and maximum concentrations encountered in two out of four lots exceeded the USEPA's threshold limit of 1200 mg kg^{-1} in nonplay areas (USEPA, 2001). The results from this study further show that remediation may be necessary, depending on the intended use of vacant space to protect public health.

The urban lots study of Montgomery et al. (2016) and the citywide study of Delbecque and Verdoodt (2016) show that lead contamination of urban soils has been the result of anthropogenic activities, raising a major human health concern that may become a major obstacle for the adoption of urban agriculture in these contaminated soils. However, a critical review of both the direct (ingestion of contaminated soil) and indirect (consumption of food grown on lead contaminated soils) exposure pathways of lead conducted by Brown et al. (2016a) shows that although high concentrations of total lead may be present in urban soils, it is highly unlikely that urban agriculture would result in elevated blood lead levels in children dwelling in the urban areas. These authors argue that best management practices adopted in urban agriculture not only reduce both direct and indirect exposure of lead but also provide health, social, and environmental benefits.

The literature presented in Brown et al. (2016a) demonstrates that the overall potential for lead uptake by plants is relatively low, resulting in very low concentrations of lead in vegetables harvested from urban sites. Recent studies have also shown that despite the presence of very high concentrations of lead in urban soil (as high as 2000 mg kg^{-1}), a very small amount may be bioavailable because the majority of lead is often present in carbonate and phosphate fractions complexed with organic matter or adsorbed to iron oxides in soil and is thus not bioavailable. In addition, Brown et al. (2016a) show that only a small amount of lead that was ingested via food may be absorbed into the blood; for example, ingestion of 1 μg lead in food for a healthy child or a healthy adult will cause only 0.16 μg dL^{-1} and 0.04 μg dL^{-1} increases in blood lead level, respectively. They conclude that the benefits urban communities may realize from urban agriculture far exceed any risks posed by elevated lead in urban soils.

In general, it is believed that the addition of organic amendments and amendments containing soluble P reduces the bioaccessibility of lead by forming lead-phosphate minerals with very low solubility in soils; however, quantifying this reduction in bioaccessibility has been a challenge. Obrycki et al. (2016) tested three modified versions of USEPA Method 1340 to assess in vitro bioaccessibility of lead in two highly contaminated soils from Ohio that were treated with six phosphate amendments. Modifications to USEPA Method 1340 include varied pH (1.5 or 2.5) of extracting solution with and without glycine. Obrycki et al.'s (2016) results show that a modified USEPA Method 1340 without glycine at pH 2.5 had the potential to predict reductions in lead in vitro bioaccessibility resulting from the addition of various P amendments to the lead contaminated urban soils.

Recovering Resources and Restoring Ecosystem Functions of Urban Soils

The environmental impact of both the urbanization and the deindustrialization of urban areas is often noticed either in a reduction in soil ecosystem services, often due to compaction or stripping of surface soil (as in urban and suburban housing or commercial development on newly acquired rural land), or in the complete absence of soil ecosystem services due to degradation caused by industrial activity. Soil ecosystem services can be restored, depending on the ultimate intended use, for example, by (i) using organic amendments available in urban areas, such as composts and biosolids, to improve the spoil material or impacted soils that are unable to support any vegetation or any functional ecosystem; (ii) recovering nutrients, especially P from wastewater as a fertilizer, which may be used in urban agriculture; or (iii) using native prairie garden plants instead of traditional turf in urban landscape to improve soils and their ecosystem functioning related to greater stormwater infiltration and sequestration of carbon deeper in the profile.

Native Prairie Gardens to Improve Urban Soils

As Johnston et al. (2016) note, restoration of tallgrass prairie biome once dominant in the midwestern United States may help in ecologically engineering urban soils to improve their functioning. They hypothesized that residential prairie gardens would have better soil physical properties compared with turfgrass lawn and that well-structured soil under prairie gardens would therefore promote infiltration and mitigate stormwater runoff. Johnston et al. (2016) tested these effects comparing soil physical properties under paired prairie gardens and turfgrass lawn by taking advantage of a "natural" experiment in which homeowners introduced prairie gardens into typical residential landscapes in Madison, WI. Results showed the surface soil beneath prairie vegetation had 10% lower bulk density, 15% lower penetration resistance, 25% greater soil organic matter, and 33% greater saturated hydraulic conductivity compared with the adjacent lawns. Overall, the results from this study show that prairie gardens improve urban soils in the long-run when converted from the typical turfgrass type of landscape.

Beneficial Use of Biosolids, Dredged Sediments, and Recovered Nutrients from Wastewater Biosolids and Dredge Materials

The water reclamation process captures wastewater from domestic, industrial, and stormwater sources from across a metropolitan region and conveys it to a central treatment plant where it is processed to meet federal and state regulatory standards for discharge, usually, to a local waterway. The main products have traditionally been reclaimed water, which is discharged from the plant, and sewage sludge, which is generally land applied as biosolids, incinerated, or sent to landfills. Biosolids consist

of sewage sludge that has undergone further treatment to meet the USEPA's 40 CFR Part 503 regulatory criteria that permit its application to land as a nutrient rich soil amendment (USEPA, 1993).

According to a national survey, approximately 6.5 million dry tons of biosolids were produced in the United States, and about 60% of that amount was land applied (NEBRA, 2007); a majority of that amount was applied to agricultural fields outside of metropolitan regions. However, utilizing biosolids to amend contaminated or low-quality urban soils would provide nutrients and organic matter for urban agriculture and produce compost for use as a soil amendment, thus capturing and retaining nutrients from the metropolitan region. Urban soils are often compacted, unnatural soils that are low in nutrients and can be significantly improved by the addition of biosolids as a soil amendment. Biosolids improve the productivity of urban soils by increasing water infiltration and retention, reducing bulk density, improving structure, and increasing the total carbon stock of the soil (Brown et al., 2011; McIvor et al., 2012).

Due to these properties and their availability in metropolitan areas, biosolids are also considered an important resource to economically revegetate brownfields as Brose et al. (2016) demonstrate. The former US Steel Corporation's South Works site in Chicago, IL, is a 230-ha brownfield situated along the southern lakefront that needed to be reclaimed to support and sustain vegetation before development. The site consisted mostly of a deep heterogeneous fill of steel mill slag materials resulting from the former iron and steel operations. It was unable to support any vegetation and thus has been vacant since the 1970s; however, parks, residential, and commercial development are now planned for the site. The slag will need to be capped with topsoil for establishing turfgrass. The Chicago Park District estimated that up to 380,000 m^3 of topsoil will be needed for new parkland planned for the site, which would be cost-prohibitive. Thus, a more cost-effective alternative was needed. Many approaches were evaluated; one of the proposed approaches to defray the revegetation cost was to substitute topsoil with locally available dredged sediments from navigable waterways (Hundal et al., 2005). Dredged sediments were shown to support crops comparable to fertile farmland soil (Darmody et al., 2004); however, low organic matter content and poor structure resulted in surface crusting and sealing on drying when sediments were used alone for establishing vegetation. The addition of biosolids was shown to mitigate this problem and had a significant positive effect on soil organic carbon, total Kjeldahl nitrogen, total phosphorous, and microbial biomass and activity 1 yr after blending with sediments (Kelly et al., 2007). The Chicago Park District and the Metropolitan Water Reclamation District of Greater Chicago considered the use of biosolids blended with sediments for capping a portion of the former US Steel Corporation's site as an option for establishing parkland vegetation, and a case study was conducted to evaluate the suitability of biosolids and dredged sediments for capping the steel mill slag to establish good quality turfgrass vegetation (Brose et al., 2016). Overall, the results from this case study demonstrate that blends of biosolids and dredged sediments could be successfully used for capping steel mill slag brownfield sites to establish good quality turfgrass vegetation. This case study provides a qualitative assessment of using exceptional quality (EQ) biosolids blended into dredged sediments as an effective cap for establishing turfgrass on steel mill slag brownfields and, thus, potentially other marginal soils. Amending sediments with biosolids provided sufficient nutrients leading to the improved performance of turfgrass. The authors recommend a conservative rate of biosolids application (50% biosolids) in the sediment blend if there is groundwater within 3 m of the underlying soil profile or surface water in close proximity to the reclamation site to ensure that water quality is not affected by excess nutrients, but they suggest that higher rates could be used when groundwater is not shallow and surface water is not in close proximity to the reclamation site.

Dredged material, either alone or in combination with biosolids, has been beneficially used in many remediation projects, and many impacted landscapes have been reclaimed and brought under various productive agricultural or nonagricultural uses. Koropchak et al. (2016) also show that sediments may be beneficially used in agriculture and urban soil reconstruction. They note that more than 200 million m^3 of dredged material is available annually from the 40,000 km of waterways the Army Corps of Engineers maintains in the United States. Only 30% the dredged material is beneficially used for habitat development, aquaculture, beach nourishment, recreation, agriculture, mine reclamation, shoreline stabilization, and industrial use in construction (Brandon and Price, 2007). The traditional approach has been to ignore the fundamental agronomic parameters and to look at heavy metals and polycyclic aromatic hydrocarbons concentrations in the dredged sediments as a screening tool for making decisions on beneficial use (Koropchak et al., 2016). Based on extensive monitoring and research in the past 15 yr utilizing fresh water and saline dredged sediments Koropchak et al. (2016) propose that the most important primary and mandatory screening parameter should be acid-base accounting and that an acceptable secondary screening should be based on a combination of federal and state residual waste and soil screening standards. In addition, basic agronomic principles should be considered. Their proposed screening system separates the beneficial use of sediments for agriculture and urban soil reconstruction into three soil quality management categories of unsuitable, suitable, and clean fill, with different monitoring requirements.

In many deindustrialized cities, vacant urban land has been degraded by the loss of topsoil, contamination, and/or soil conditions such as salinity, acidity, or compaction or in short urban soils that may have lost their ecosystem function to support plant or microbial life. In general, the addition of organic soil amendments, such as biosolids, manure, and composts, restores soil ecosystem functioning. The work of Brose et al. (2016) clearly shows that by using biosolids and dredged sediments, it is possible to grow plants even on steel mill slag and that with time, fertility of the soil improves. Basta et al. (2016) address the use of biosolids and composts used successfully to improve soil ecosystem functioning of the Lake Calumet Cluster Site in Calumet, IL, a Superfund site impacted by heavy industry in the region. The authors evaluated four treatments: (i) biosolids at 202 Mg ha^{-1}, (ii) biosolids at 404 Mg ha^{-1}, (iii) compost at 137 Mg ha^{-1}, and (iv) a blend consisting of biosolids applied at 202 Mg ha^{-1}, drinking water treatment residual, and biochar. The amended soils were planted with a native mix of plants containing grasses, legumes, and forbs. Results of the study show that all soil amendments improved soil quality and nutrient pools, established a

dense and high quality vegetation cover, improved earthworm reproductive measures, and increased soil enzymatic activities that support soil function. Basta et al. (2016) note that overall, biosolids outperformed compost. Although several microconstituents (i.e., pharmaceuticals and personal care products) were detected in runoff, the concentrations were below the probable no-effect levels, demonstrating that the use of biosolids would not pose any impact on the aquatic environment. The authors recommend that the use of best management practices, such as runoff control measures to prevent sediment loss until the establishment of vegetation, would further help in addressing some of these concerns at the sites being restored.

Recovering Nutrients from Wastewater for Reuse

Improving the fertility of urban soils should not be a problem as cities are centers of resource consumption and as a result generate a wide variety of by-products (e.g., plant residues, kitchen waste, old newspapers, tree leaves, biosolids) that could be composted and applied to urban soils (Fig. 1, modified from Brose et al., 2014). A large amount of nutrients is brought to the cities in the form of food from neighboring rural areas and from around the world. A significant proportion of these nutrients is released in human feces and urine that are sent to WWTPs (Brose et al., 2014). On average, 0.6 kg P is excreted per year per person, and a major proportion (~58%) of this is excreted in the soluble form in urine (Kumar et al., 2012). High concentration of P in effluent discharged from WWTPs may cause eutrophication of surface waters (De-Bashan and Bashan, 2004; Parsons and Smith, 2008). Due to stringent regulations imposed on WWTPs, many municipalities have invested in P recovery technologies to harvest struvite, magnesium ammonium phosphate ($MgNH_4PO_4.6H_2O$) fertilizer. These technologies offer sustainable option for reducing P-loading in receiving waters as well producing biosolids with relatively favorable P/N ratio. In their study, Venkatesan et al. (2016) modeled the feasibility of P recovery from a typical WWTP serving a population of 160,000 in Arizona. Modeling results showed that about 71 to 96% of the P being lost in effluent discharge could be recovered, resulting 491 ± 64 t yr^{-1} of struvite fertilizer. The amount of P recovered from this WWTP could fertilize about 2000 ha of agricultural land. The study conducted by Venkatesan et al. (2016) shows that there is a potential of recovering between 20 and 50% of excreted P in the form of struvite; the process was projected to be economically feasible for WWTPs with a payback period of ~3 yr. Furthermore, for every 1 t struvite production, approximately 10 t CO_2 equivalent emissions would be offset compared with conventional fertilizer production. Thus, not only can the nutrients be recovered from the waste right where it is generated, but they can also be utilized where the demand is, reducing the import of nutrients from distant places.

Benefits of Urban Green Spaces

Thermal Comfort

Greening of the urban land vacated due to the deindustrialization of metropolitan areas may provide several environmental benefits. One such benefit is improvement of the thermal comfort condition of city residents during peak summer months by mitigating the urban heat island effect. The study conducted by Brandani et al. (2016) provides useful information on thermal regimes of urban soils and surfaces and demonstrates that exposed surfaces became less heated if their albedo was high, which led to significant reduction in surface temperatures even under the sun's direct exposure. The authors compared four different surfaces, showing that green surfaces were always cooler than asphalt, gray sandstone, and white gravel, as indicated by lower daytime surface and air temperatures. Thus, replacing impervious land surfaces with green groundcover is important to improving thermal comfort during the peak summer months in the city, and urban planners and policymakers must take heed of this while developing urban transformations and renovation plans.

Urban Soils and Stormwater Management

Development and urbanization have altered the drainage system of most metropolitan areas by increasing the impermeable surfaces at the cost of green permeable surfaces, resulting in greater volumes of stormwater runoff and flashier storm peaks, which overwhelm the capacity of combined sewers and cause localized flooding, flow surge to the downstream WWTPs, and combined sewer overflows to receiving waters (Kumar et al., 2016). Recently, the focus has been shifting from "end-of-pipe" type traditional drainage systems to more sustainable drainage systems often referred to as "green infrastructure" (GI) for managing stormwater runoff. The general principle behind the idea of GI technologies is simply "collect, treat, and freely infiltrate stormwater to recharge groundwater" such that the stormwater bypasses the collection system sewers. In comparison to traditional drainage systems, GI technologies, like bioretention systems (rain gardens, bioswales, planter boxes), are deemed sustainable and are often cost-effective for urban areas (Center for Neighborhood Technology, 2010).

These systems use soil to enhance stormwater (runoff from surrounding impervious surfaces) infiltration into the soil. The soils used in the bioretention systems, while supporting plant growth, must also be capable of rapid water infiltration and have high retention or filtration capacity for stormwater pollutants and reducing pollutants being conveyed to surface water bodies via WWTPs, hence reducing the impact of the "first flush" effect that is commonly associated with urban runoff (Rajapakse and Ives, 1990; Andersen et al., 1999; Kumar et al., 2016). Urban stormwater may contain a wide range of contaminants, including particulates, nutrients, metals, and organic matter like fats, oils, and grease. In general, the focus has been on heavy metals and nutrients as contaminants in urban runoff, and the reported concentrations have been typically <1 mg L^{-1} and <2 mg L^{-1}, respectively (Brown et al., 2016b). Removal efficiencies or retention of these pollutants will depend on the characteristics of soils used in the GI retention systems. Brown et al. (2016b), referring to a review of soil specification from 16 states by Carpenter and Hallam (2010), indicate that composition of soils used in GI systems varies from 30 to 60% sand, compost ranging from 20 to 40%, and top soil ranging from 20 to 30%.

In their study, Brown et al. (2016b) propose that the P saturation index (PSI) could be used as a tool to evaluate whether the soil mixes used in GI systems could become a sink or source of nutrients, like N and P, and also of metals, like Zn and Cu. The PSI was developed as a predictive tool to determine the potential

of P leaching from soils amended with organic residuals like manures and biosolids (Elliott et al., 2002; Agyin-Birikorang and O'Connor, 2007) and is based on a strong correlation between the ratio of total P to Fe and Al oxides as determined by oxalate extraction ($PSI = P_{ox}/(Fe_{ox} + Al_{ox})$) and the P found in leachate. Brown et al. (2016b) evaluated three different composts adjusted with Fe-based drinking water treatment residuals and P salts to PSI values of 0.1, 0.5, and 1.0 on nutrient and metal leaching using a synthetic stormwater solution and also evaluated plant performance. Results indicate that compost from manure/sawdust performed poorly in terms of plant performance. The PSI proved to be an effective tool to predict P movement in GI soils. Although all compost materials tested showed high contaminant removal, removal of metals was much higher when PSI of the soil mix was low.

If, however, the soil mixes show a high contaminant removal or, in other words, the metal contaminants are retained in the soil mix, an important question arises as to whether the concentration of metals in the GI soil will exceed the threshold for human health impacts of urban soil remediation standards due to the long residence time of metals in soils. This may have important implications for the people who manage these systems or the public who may come in contact with these systems. Thus, it is important to study the accumulation of elements of concern in GI soils, as pointed out by Kondo et al. (2016). These authors rightly point out that most GI projects are located on public or institutional lands, such as street right-of-ways, in parks, or school grounds and that due to their location, it is important to characterize GI soils in relation to human exposure and health risks. Kondo et al.'s (2016) study provides a unique and much needed evaluation of soil elemental concentrations in GI projects constructed over a decade in Philadelphia, PA. Soil elemental concentrations, categorized as macro- and micronutrients, heavy metals, and other elements at 59 GI sites and soil samples 3 to 5 m upland of these sites were compared. The comparisons were adjusted for the age of GI, underlying soil type, street drainage, and surrounding land use. The results indicate only calcium and iodine concentrations were significantly higher than background levels at GI sites, which might be the result of winter deicing salt from road runoff to GI soils. These elements do not pose a human health risk.

Summary and Recommendations

The collection of papers published in this special section highlights the need to educate the public and policymakers about urban soil quality. Characterization of urban soils in relation to priority pollutants is the first step for decision making for their intended use to provide various ecosystem services. Results presented in these papers clearly indicate that although urban soils may be degraded and contaminated, the soils could be improved or restored to provide various ecosystem services by simply amending them with locally available resources such as composted municipal solid waste, dredged sediments, and wastewater treatment residuals like biosolids and also by reusing nutrients (e.g., struvite fertilizer) recovered from wastewater. These kinds of locally available resources, once seen as waste materials, are becoming valuable for improving the quality of urban soils in a more sustainable manner. From the presentations made at the "Soil in The City—2014" conference held in Chicago, and from this extraordinary collection of papers, we highlight the following recommendations:

- The industrial revolution during the early 20th century and deindustrialization of urban cities in the last three decades throughout the world left a legacy of heavy metal contamination in the urban soils. There is an urgent need of establishing an urban heavy metal accumulation baseline not only for developing ameliorative approaches but also for monitoring and evaluating future changes in urban soil quality.
- Although an elevated level of lead could be present in many urban soils, only a fraction of it is bioaccessible and may not pose any elevated risk for adverse human health. The best management practice of adding organic amendments in urban gardens to grow crops under adequate soil nutrient levels has been shown to reduce the bioavailability and bioaccessibility of soil lead. It is now widely accepted as a remediation method for urban soils.
- Modified USEPA Method 1340 without glycine and extracting solution pH of 2.5 has the potential to predict reductions in lead bioavailability resulting from the addition of various P amendments to the lead-contaminated urban soils.
- Planting prairie gardens may improve urban soils in the long term when converted from typical turfgrass, and urban soils may provide improved ecosystem services including higher carbon sequestration and improved stormwater management in urban landscapes.
- Biosolids, compost, and dredged sediments are important and sustainable locally available resources to improve degraded urban soils. In addition, mixtures of biosolids and dredged sediments can be used for greening brownfields.
- Nutrients may be recovered from wastewater right where it is generated and also utilized where the demand is, reducing the import of nutrients from distant places. There is potential of recovering a significant proportion of excreted P in the form of struvite from WWTPs if enhanced biological P removal coupled with P recovery is adopted.
- Greening/farming of the urban land vacated due to deindustrialization of metropolitan areas may improve the thermal comfort condition of city residents during peak summer heat waves by mitigating the urban heat island effect.
- Characterizing soils used in the green infrastructure stormwater management projects is important to ensure that they act as a sink for legacy pollutants received in runoff from the catchment areas. The PSI of different soils amended with compost and biosolids was shown to be an effective tool not only to predict P movement in green infrastructure soils but also to retain heavy metals. Most green infrastructure projects for stormwater management are located on public or institutional lands, such as street right-of-ways, in parks, or school grounds. Due to their location, it is important to characterize soils in relation to human exposure and health risks.

Conclusions

There is a need to develop the local knowledge and skills for managing and improving urban soils so that the urban soils provide the required ecosystem functioning. These skills must integrate knowledge from agronomic, ecological, environmental, economic, and social sciences for increasing urban food production, greening of urban landscape, and green infrastructure for stormwater management with the overarching objective of not only improving the nutrition and health of urban populations but also improving the overall environment and living conditions of urban communities.

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