Characterizing Minimally Disturbed Soils in a Highly Disturbed Urban Environment

Tania D. Burgos Hernández,* Brian K. Slater, and Jared M. Shaffer

Core Ideas
- Historical maps were used to identify two undisturbed soil pedons in the urban area.
- Strong correlation was found between dolomite and the very coarse and coarse sand fractions.
- The $\text{Y}_2\text{O}_3/\text{ZrO}_2$ ratios of soil minerals can be used to identify disturbance boundaries.

Abstract
Urban soils are often highly disturbed by anthropogenic activity, and consequent impacts on soil function are not well understood. Minimizing the disturbance of highly modified soils, including those at The Ohio State University, will decrease local C footprints. The main objective of this study was to locate and characterize relatively undisturbed soils in the urban study area to use as a baseline for comparison with a wider range of sampled profiles. Historical campus maps were used to locate and sample three areas where building footprints indicated that minimally disturbed soils might be found. Pedon 1 was classified as a Celina silt loam (fine, mixed, active, mesic Aquic Hapludalfs) and Pedon 2 as an Eldean silt loam (fine, mixed, superactive, mesic Typic Hapludalfs). Pedon 3 exhibited evidence of significant disturbance due to the presence of foreign materials and disrupted horizonation. Pedon 3 had the highest percentage of total C of all three sites at 0- to 70-cm depth due to the presence of asphalt. In Pedon 2, most of the total C from the BC horizon and below was inorganic C derived from calcareous glacial outwash parent material. Pedon 1 showed a mostly homogeneous parent material due to the consistent geochemical ratios throughout the soil profile. There were abrupt horizon discontinuities in Pedon’s 2 and 3 ratios indicating heterogeneity of materials. Establishing baseline soil characteristics shows how urban soils have been modified over time and provides information for policymakers to understand the urbanization of soil environments and to enhance ecosystem services.

Abbreviations: $\rho_b$, bulk density; CC, coarse clay; CCE, calcium carbonate equivalent; CS, coarse sand; CSI, coarse silt; EC, electrical conductivity; FS, fine sand; MS, medium sand; POXC, permanganate oxidizable carbon; SOC, soil organic carbon; TC, total carbon; TN, total nitrogen; VCS, very coarse sand; VFS, very fine sand.

As population in urban environments keeps growing, the impact of human activities on ecosystems increases (Seto et al., 2011). A decrease in landscape vegetative cover from natural to urban environments could have a negative effect on biodiversity by loss of habitat, the capacity of soil to store C, reduction of biomass, and loss of farmland and wetlands (Hasse and Lathrop, 2003; McKinney, 2002; Seto et al., 2012). Anthropogenic activities directly affect soils in urban environments by increasing concentrations of metals and other pollutants (Szolnoki et al., 2013), increasing the loss of natural resources (Deelstra and Girardet, 2000), and altering C, N, and biochemical cycles (Lorenz and Lal, 2009). The expansion of urban areas demands better understanding of human modified pedogenesis and transformation in disturbed areas, especially since researchers are only beginning to understand how ecosystem dynamics are affected by urbanization (Kaye et al., 2006).

Humans have impacted soils in urban environments by developing and constructing artificial soils, covering natural soils, and extraction of material normally not affected by surface processes (IUSS Working Group WRB, 2006). In general terms when referring to urban soils, they are usually viewed as drastically disturbed soil material of low fertility (Craul, 1999) that often are developed from a mixture of natural and anthropogenic substrates (Morel et al., 2005; Nehls et al., 2013). The study of urban soils has increased greatly as the interest in understanding their characteristics has increased (Madrid et al., 2008). Urban soils are highly complex, unique, and variable environments that are not well understood (Wong et al., 2006) because they are directly affected by human activities and depend on

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patterns of development and the magnitude and pattern of environmental change (Pouyat et al., 2003). The effects of environmental and management factors on urban soils can be categorized as direct or indirect effects (Pouyat and Effland, 1999). Examples of direct effects include physical disturbances, incorporation of anthropic materials, burial or coverage of soil by fill material and impervious surfaces, and soil management practices introduced after the initial development disturbance. Indirect effects include urban heat islands, soil hydrophobicity, introduction of exotic plant and animal species, and atmospheric deposition of pollutants. Previous activities that took place on urban soils may be completely hidden or buried and it is not a simple task to identify them. Urban soils, in most cases, present high spatial heterogeneity, profile variability, and layer discontinuities due to the strong human influences (Cadenasso et al., 2007; Huot et al., 2015; Pouyat et al., 2010). These heterogeneities in urban soils are observed both horizontally and vertically through soil profiles and across urban landscapes (Raciti et al., 2011).

Traditional soil survey methods can be modified and applied to examine soils in urban environments (De Kimpe and Morel, 2000; Morel et al., 2005). Characterization of soils in urban environments is of high importance because their properties could diverge from comparable soils in natural environments, and these impacts influence critical ecosystem services. Properties and pedogenesis in urban environments are dominated by the anthropogenic influence (Lehmann and Stahr, 2007) and the effects of urbanism can occur across various spatial scales (Pouyat et al., 2010). The variability found in surface soils from urban environments makes the description of a common urban soil challenging (Pouyat et al., 2010). Soils in urban areas are subjected to pedogenic factors that control their transformation and evolution similar to natural soils (Huot et al., 2015; Sére et al., 2010); however, human activity dictates the pace at which these transformations will happen (De Kimpe and Morel, 2000). Consequently, disturbance effectively resets the onset of pedogenesis to the time of major impact, and high rates of soil development may ensue during the first stages of weathering (Huot et al., 2015).

In Baltimore, MD, Pouyat et al. (2007) studied the effect of land use and cover on surface-soil properties and found that chemical properties generally varied more than the physical properties. They also found that the variation of these properties makes the description of a typical urban soil difficult. However, K, P, bulk density, and pH had a discernable pattern with land-use and cover types, for example, differentiating forested covered areas vs. turf-grass in residential areas. Researchers have shown that in urban areas, the chemical composition of soil organic matter is significantly different compared with natural soils (Beyer et al., 2001), with lower humic compounds and higher aromatic C contents. Kaye et al. (2005) compared urban lawns to corn (Zea mays L.), wheat (Triticum aestivum L.)—fallow, and unmanaged shortgrass steppe and found that the spread of urban areas in arid and semiarid ecosystems leads to enhanced C cycling rates that are large enough to alter regional C budgets. They observed 2.5 to 5 times greater soil respiration and total belowground C allocation in urban ecosystems than the other land-use types. However, Doichinova et al. (2006) found higher C content in soils from semi-urban areas compared with urban soils. Researchers have found soil physical, chemical, and biological properties in urban ecosystems improve over time from the initial disturbance, in this case an average of 64 yr (Scharnbroch et al., 2005). Specifically, they showed lower bulk density and higher biological activity and soil organic matter.

To help understand the extent of the disturbance of urban soils, historical maps may be used to identify previous construction in an urban area. The use of these maps allows for the location of areas where minimal activity has (likely) occurred. These minimally disturbed areas could then be used as an exemplar of the more natural development of soils in the area. In this study we aimed to: (i) find relatively undisturbed soils in the urban study area to use as a reference for future studies, and (ii) use USDA soil taxonomic methods to characterize and classify these urban soils.

**MATERIALS AND METHODS**

**Study Area**

The study area was on the Ohio State University campus, a large urban institution in Columbus, OH. Columbus has a population of 860,090 (1399 people km$^{-2}$; US Census Bureau, 2017), with the university itself having more than 91,000 students and employees (Ohio State University, 2016). The region experiences a humid continental climate, receiving 998 mm of precipitation annually and average annual daily minimum and maximum temperatures of 6.8 and 17°C, respectively (Arguez et al., 2010). Although the 770.5-ha (1904-acre) campus was founded in the 19th century as an agricultural community along the Olentangy River, the area is now highly developed and covered by approximately 45% impervious surface (Homer et al., 2015).

The dominant soils in the campus area are urban land complexes with Hapludalfs and Udorthents (Soil Survey Staff, 2017) mapped. The soils were originally developed from glacial outwash, alluvium, and loamy glacial till, from the late Wisconsinan age. Undisturbed soils tend to be deep and well-drained, with silt loam and silt clay loam texture. Originally, the area was dominated by deciduous forest, such as oak (Quercus sp.). After urbanization, however, the landscape is mainly lawn turf and parklands, with scattered patches of tree stands, interspersed between structures and constructed surfaces.

**Site Location**

Fourteen maps from when the university was founded in 1876 until present times were located at the university archives (Fig. 1). These maps were scanned, digitized, georeferenced, and used as reference points to determine how the location of building structures and other infrastructure has changed over time. These maps were used to define where undisturbed areas are most likely to be located. Three main areas were located where no buildings had been established according to the campus maps, to open soil pits and to sample and characterize the soil.

**Sampling**

Three soil excavations were opened on the west campus of The Ohio State University (OSU) in November 2016: (i) 40°0’21” N, 83°1’44” W; (ii) 40°0’14” N, 83°1’34” W; and (iii) 40°0’12” N, 83°1’27” W (Fig. 1). Ponds 3 was dug approximately 15.24 m (50 feet) away from where originally planned, as the original location is now an athletic field used by the OSU teams, and access could not be granted. The pits were approximately 1.2 m deep, and six horizons were identified in each pit (Fig. 2). Horizons were characterized for structure, color, and rock fragments (Schoeneberger et al., 2012), and a single bulk density sample was collected for each horizon using the core method (Blake and Hartge, 1986). Bulk soil samples were collected for each horizon for further analysis, passed through...
a 2-mm sieve, and dried at 50°C. Soil horizons were classified following USDA Soil Taxonomy (Soil Survey Staff, 1999). To emphasize human artifacts in soil horizon characterization, human-transported material was denoted by the carat (^) symbol and horizons formed in human-altered material were designated by the asterisk (*) symbol, as in Howard (2017).

Soil Characterization and Analysis

Bulk soil samples collected from the pedons were characterized for physical and chemical properties.

Physical Properties

Bulk Density

Undisturbed soil core samples of a 5.4-cm diameter and 6.4-cm length were collected for each soil horizon to determine bulk density (ρb). Bulk density was determined using the core method (Blake and Hartge, 1986) and corrected for coarse fragments.

Texture

Previously air-dried and sieved soil (<2-mm fraction) was used for particle-size analysis following the pipette method (Gee and Bauder, 1986), and medium silt (MSI, 20-μm), fine silt (FSI, 5-μm), total clay (2-μm), and fine clay (FC, 0.2-μm) fractions were determined. Sand fractions were measured using a nest of sieves with 1000-, 500-, 250-, 125-, and 62.5-μm mesh, corresponding to very coarse sand (VCS), coarse sand (CS), medium sand (MS), fine sand (FS), very fine sand (VFS) fractions.

Chemical Properties

pH and Electrical Conductivity

Electrical conductivity (EC) was measured using an EC meter in a 1:1 soil/water solution. After EC was measured, 10 mL of CaCl₂ 0.02 M was added to measure the 1:2 CaCl₂ pH.

Total Carbon and Total Nitrogen

Sieved dry soil samples were ground with a mortar and pestle then heated at 1000°C in an elemental analyzer (Carlo Erba CHN EA 1108, now Thermo Fisher Scientific, Waltham, MA) under a stream of oxygen to determine soil total carbon
(TC) and total nitrogen (TN). Fresh samples were acid-washed for 24 h with 1 M HCl to remove inorganic C and passed again through the analyzer (Usrii and Lal, 2008).

### Organic Carbon by Dichromate Oxidation

Organic C was determined by the dichromate oxidation method (Heanes, 1984). Soil samples were mixed with a K₂Cr₂O₇ and H₂SO₄ solution, heated in a MARS 1600-W microwave for 30 min at 135°C, then were analyzed on a spectrophotometer at 600 nm.

### Permanganate Oxidizable Carbon

Permanganate oxidizable carbon (POXC) was measured following Weil et al. (2003). Deionized water and 0.2 M KMnO₄ were added to each sample, then the supernatant was dispensed into a microplate and read on a plate reader.

### Calcite and Dolomite

Calcite and dolomite was performed using the Chittick apparatus (Dreimanis, 1962; Loeppert and Suarez, 1996), and HCl was added to the soil samples over 30 s and the volume of CO₂ produced was measured, corresponding with the calcite concentration. The CO₂ volume was measured again after 30 min, corresponding with the dolomite concentration.

### Total Metals

Total metals were analyzed using a Thermo Scientific Niton FXL-959 FM-XRF Analyzer (XRF), which is a nondestructive technique. An unweighed, air-dried, and ground soil was placed in a plastic sample bag. The bag was placed on the XRF scanner and total metal (Al, As, Ba, Ca, Cd, Co, Cr, Cu, Fe, K, Mg, Mn, Mo, Ni, P, Pb, Sc, Sr, Ti, U, V, Y, Zn, and Zr) concentrations were measured.

### Equal-Area Splines

An equal-area spline was fit to each soil profile dataset using the GSIF package for R (Hengl, 2019; R Core Team, 2018). This technique results in a depiction of the continuous variation of the soil attribute down the profile while preserving the mean values of the sampled horizons. Rather than describing the soil attributes as a stepped depth function, we used equal-area spline to make soils data more continuous.

## RESULTS AND DISCUSSION

### Soil Morphology

Horizon sequences and colors are shown in Fig. 2 (Beaudette et al., 2013) and morphological descriptions are listed in Table 1.

### Table 1. Morphological characterization for Pedons 1, 2, and 3.

<table>
<thead>
<tr>
<th>Pedon 1: Aquic Hapludalf</th>
</tr>
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<tbody>
<tr>
<td><em>Ap1</em> 0–10 cm; dark grayish brown (10YR 4/2); many roots; strong and fine granular structure; friable; 1% subrounded/subangular rock fragments; abrupt smooth boundary.</td>
</tr>
<tr>
<td><em>Ap2</em> 10–22 cm; brown (10YR 4/3); weak medium and fine subangular blocky/granular structure; 1 to 5% asphalt fragments; 10% subrounded to angular tabular rock fragments; abrupt smooth boundary.</td>
</tr>
<tr>
<td>Bt1 22–59 cm; dark yellowish brown (10YR 4/4); few dark grayish brown (10YR 4/2) earthworm channels and clay films; moderate medium and subangular blocky structure; firm; 1% rock fragments; clear boundary.</td>
</tr>
<tr>
<td>2Bt2 59–83 cm; yellowish brown (10YR 5/4); angular and tabular structure; very firm; 2% Mg cutans; many clay films; few medium distinct red (5YR 5/6) concentrations; common distinct brown (7.5YR 5/3) depletions; 5% subangular 1- to 5-cm rock fragments; clear boundary.</td>
</tr>
<tr>
<td>2BtC 83–116 cm; yellowish brown (10YR 4/4); weak and subangular blocky structure; many clay films; common distinct brown (10YR 5/3) depletions; fine and prominent red (5YR 5/4) concentrations; 5% subangular 2-cm rock fragments; abrupt boundary.</td>
</tr>
<tr>
<td>C 116–127 cm; brown (10YR 4/3); fine to medium till; massive; 35% rock fragments.</td>
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<tr>
<th>Pedon 2: Typic Hapludalf</th>
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<tbody>
<tr>
<td><em>A</em> 0–17 cm; dark grayish brown (10YR 4/2); disturbed/transported material; many roots; strong medium and granular structure; bottom half weak medium platy structure; 1% rock fragments; clear boundary.</td>
</tr>
<tr>
<td><em>BA</em> 17–34 cm; dark grayish brown (10YR 4/2); moderate medium and subangular blocky structure; firm; few roots; 2% asphalt fragments; 5% subangular subrounded rock fragments from 1 to 10 cm; calcareous and quartz; clear boundary.</td>
</tr>
<tr>
<td>2Bt 34–68 cm; dark grayish brown (10YR 4/2); moderate medium and subangular blocky structure; 30% 1- to 4-cm subrounded tabular and subrounded rock fragments; calcareous rock; clear boundary.</td>
</tr>
<tr>
<td>2BC 68–89 cm; dark grayish brown (10YR 4/2); weak medium and subangular blocky structure; 60% subangular and tabular subrounded rock fragments; gradual boundary.</td>
</tr>
<tr>
<td>2C 89–113 cm; grayish brown (10YR 5/2) medium sand; single grain and loose structure; 3% rounded 0.5- to 3-cm rock fragments; abrupt boundary.</td>
</tr>
<tr>
<td>3C 113–130 cm; light yellowish brown (10YR 6/4) stratified silt; massive; firm.</td>
</tr>
</tbody>
</table>

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<tr>
<th>Pedon 3: Typic Hapludalf</th>
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</thead>
<tbody>
<tr>
<td>^Ap 0–11 cm; light brownish gray (10YR 6/2); strong and fine granular structure; many roots; very friable; 70% 0.5- to 3-cm angular tabular rock fragments; abrupt boundary.</td>
</tr>
<tr>
<td>^AC 11–32 cm; black (10YR 2/1); weak and subangular blocky structure; 50% rock fragments and asphalt; abrupt boundary.</td>
</tr>
<tr>
<td>^Cu 32–45 cm; dusty red (10R 3/4) material; ceramic artifacts, massive, 60% rock fragments, largely black (10YR 2/1) asphalt; from 40 to 45 cm brown (10YR 4/3); 65% 1- to 3-cm calcareous gravel, abrupt, massive; abrupt boundary.</td>
</tr>
<tr>
<td>2Bt1b 45–69 cm; brown (7.5YR 4/3); moderate and medium subangular blocky structure; clay films; 2% 3-cm angular rock fragments; clear boundary.</td>
</tr>
<tr>
<td>2Bt2b 69–100 cm; brown (7.5YR 4/3); moderate and medium subangular blocky structure; 30% 0.5- to 5-cm subrounded rock fragments; gradual boundary.</td>
</tr>
<tr>
<td>2BC 100–120 cm; brown (7.5YR 4/3); weak and medium subangular blocky structure; clay films; 5% 5- to 15-cm rounded rock fragments.</td>
</tr>
</tbody>
</table>
Fig. 3. Soil bulk density (g cm\(^{-3}\)) by soil depth (cm) from the three pedons.

Fig. 4. Coarse fragments (%) >2 mm by soil depth from the three pedons.

Fig. 5. Texture triangle for the horizons of all three pedons.
Bulk Density and Coarse Fragments

Soil bulk density (rb) by depth in all three pedons is shown in Fig. 3. In Pedon 1, rb was 1.04 g cm\(^{-3}\) at the soil surface and 0.92 g cm\(^{-3}\) at the lowest measured depth of 127 cm. Bulk density in Pedon 2 ranged from 1.06 g cm\(^{-3}\), with 1.12 g cm\(^{-3}\) at the surface, to 1.60 g cm\(^{-3}\). The highest rb was observed in the 3C2 horizon and the lowest in the *BA horizon. Pedon 3 had a low bulk density value at the soil surface, 0.87 g cm\(^{-3}\). Due to the massive (structureless) condition at the 32- to 45-cm depth (^Cu horizon) in Pedon 3, we were not able to take a bulk density sample.

Soil coarse fragments by depth in all three pedons is shown in Fig. 4. In Pedon 1 coarse fragments increased with depth. It ranged from 0% at the soil surface to 30% at the C horizon. Pedon 2 coarse fragments varied by horizon, with the surface and 3C2 horizon showing the lowest coarse fragments, 4 and 5%, respectively. The four horizons between the surface and the 3C2 horizon had on average a 24% coarse fragments. Coarse fragments in Pedon 3 at the soil surface were the highest compared with the other two pedons with 48% coarse fragments. This pedon had the highest coarse fragments in the 2BC horizon, with 64% and the lowest in the 2Bt1b horizon of 5%. The ^Cu horizon was not sampled due to its structureless condition.

Texture

Soil texture is depicted in Fig. 5 and Fig. 6. In Pedons 1 and 2, silt was the particle size in highest proportion and clay the lowest. In Pedon 3, sand was the most common particle separate and clay the least. Pedon 1 shows relatively equal proportions of all the soil separates, with four horizons classified as loam. Pedon 2 has most of the profile classified as silt loam. However, 2BC and 2C1 were classified as coarse sandy loam due to a higher amount of sand in these two horizons compared with the other two separates; specifically, CS was the dominating fraction. Coarse sandy loam is the most common soil texture class in Pedon 3. Pedon 3 had higher sand content than the other two pedons. Coarse clay (CC) was consistently higher in all horizon in all pedons.

Electrical Conductivity

Electrical conductivity (Fig. 7) did not exceed 1 dS m\(^{-1}\) at any soil horizon in any pedon. Pedons 1 and 2 showed the highest EC at the soil surface, whereas Pedon 3 had the highest EC at horizon *Cu (0.749 dS m\(^{-1}\)). Pedon 1 had the highest recorded EC from the three pedons (0.833 dS m\(^{-1}\)). Electrical conductivity decreased with depth until horizon 2BtC where it slightly increased. Electrical conductivity in pedons varied for each soil horizon.
without a definitive pattern. In Pedon 3, EC was relatively the same through the soil profile, except for the \(^{Cu}\) horizon.

**Total Carbon and Total Nitrogen**

Soil TC (Fig. 8) in Pedon 1 was highest at the surface (3.8%) and it decreased with soil depth. Pedon 1 had a TC lower than 2% from the 22-cm depth. In Pedon 2, TC increased for the 2BC and 2C1 horizons. The highest percentage of TC in Pedon 2 was in the 2C1 horizon (6.1%) and the lowest in the 3C2 horizon (1.0%). Pedon 3 had the highest percentage of TC for all three pedons at the soil surface through the 70-cm depth. At the soil surface, TC in Pedon 3 was 11.5% followed by 12.6% at the \(^{AC}\) horizon. The lowest TC on Pedon 3 was at the 2Bt2b (1.4%).

Soil TN (Fig. 9) was the highest in Pedon 3 compared with the other pedons, following a similar pattern to TC. Total N decreased with soil depth in Pedon 2 and Pedon 3. However, in Pedon 1, TN decreased with soil depth until horizon 2C, where it had a slight increase. The highest TN at the soil surface was observed in Pedon 3 (0.5%). The lowest TN was observed in Pedon 2 in soil horizons 2C1 and 3C2, with 0.03% each.

**Soil Organic Carbon**

Soil OC (Fig. 10) decreased with soil depth in Pedons 1 and 2. However, in Pedon 3 an increase in SOC was observed in the \(^{AC}\) horizon with 12.5%. In Pedon 1 and 2 the highest SOC was at the soil surface with 3.6 and 3.3%, respectively. The lowest SOC in Pedon 2 was in the 3C2 horizon with 0.6%. In the Pedon 3 the lowest SOC was observed at the 2Br2B horizon with 1%.
Permanganate Oxidizable Carbon

Permanganate oxidizable C by depth in all three pedons is shown in Fig. 11. Permanganate oxidizable C was highest at the soil surface, and in general decreased with depth. Pedon 3 had the highest POXC at the soil surface (0.1%) of all three pedons. In Pedon 1, POXC ranged from 0.02% at the bottom horizon to 0.09% at the surface. In Pedon 2, POXC ranged from 0.01% at the bottom horizon to 0.07% at the surface.

Inorganic Carbon and pH

Figure 12 is showing the percentage of calcite, dolomite, and the calcium carbonate equivalent, soil pH by soil depth. In Pedon 1 soil the highest soil pH was observed at the *Ap2 horizon with a pH of 7.4 and kept decreasing with depth. In Pedon 2 soil pH increased with depth from 6.5 at the soil surface to 7.9 at the bottom horizon. In Pedon 3 pH varied with depth with a range of 6.8 to 7.3. The highest pH was observed in the 2C1 and 3C2 horizons in Pedon 2 (7.9).

Pedon 1 had the highest calcite and dolomite percentage at the *Ap2 horizon, 1.7 and 3.8%, respectively. Thus, the higher CCE was at this same soil horizon. There was no calcite or dolomite under the 2Bt2 horizon in Pedon 1. In Pedon 2 calcite and dolomite increased with soil depth until it reached horizon 3C2. Calcite was the highest in the 2C1 horizon (7.3%) and dolomite was the highest in the 2BC horizon (15%). Pedon 3 had 29.6 and 28.4% calcite and dolomite in the ^Ap horizon. These percentages decreased in the deeper horizons.
Total Metals

Total elements by soil horizon in all three pedons is shown in Table 2. In Pedon 1, Al and Ca were highest in the lowest horizon. In this pedon, Pb highest concentration was in the *Ap1 horizon, 55 mg kg⁻¹. All the soil horizons in the three pedons had As levels higher than 19 mg kg⁻¹. The highest concentration of As was observed in Pedon 3 in the *AC horizon, 62 mg kg⁻¹. Pedon 3 had the highest levels of Pb from the three pedons, with horizon ^AC having 518 mg kg⁻¹ Pb.

Bulk Density, Coarse Fragments, and Texture

Soil properties are directly impacted by and subjected to modifications in urban environments due to the infrastructure that surrounds them (Scharenbroch et al., 2005). Due to these modifications, soil properties could be highly variable in an urban setting. Researchers have measured both high bulk density (>1.6 g cm⁻³) (Jim, 1998a) and low bulk density (<1.0 g cm⁻³) (Strain and Evans, 1994) in urban soils, which shows the variability of these soils. Scharenbroch et al. (2005) found that soils in urban landscapes that have been in place for an average of 64 yr had 1.41 g cm⁻³ pb compared with 1.73 g cm⁻³ in soils with a mean landscape age of 9 yr, and 1.39 g cm⁻³ in park sites at the 15-cm depth. Pedon 2 had the highest pb for the uppermost horizon of 1.12 g cm⁻³ for all pedons and horizons. All the pedons had lower pb at the soil surface than that reported by Scharenbroch et al. (2005). Calhoun et al. (2001) found that Ohio soils in general have a mean pb of 1.50 g cm⁻³, which was determined using prediction models created from a dataset of 937 horizons; these were mostly agricultural soils. We found a low pb in Pedon 3, which we attribute to the presence of crushed asphalt, which was evidenced by the 48% coarse fragment content. In general, the mean soil pb for the three pedons were 1.12, 1.25, and 0.78 g cm⁻³, which is lower than the average for the state. Bulk density was lower than typical for the parent material horizons, especially the glacial till material in Pedon 1. In a study done on a relatively undisturbed lawn in the grounds of a university campus, in the city center of Liverpool, UK, Beesley (2012) found pb of 1.55 g cm⁻³ on two of the three sites and 1.29 g cm⁻³ on the third site. Lu et al. (2005) estimated an average pb of 1.55 g cm⁻³ in urban soils in Shenzhen City and approximately 30% soil gravel content (>2 mm) in th 0- to 20-cm soil depth.

Pedon 3 had a coarse sandy loam texture in the ^Ap, ^AC, and ^Cu horizons. Disturbed urban soils often have a comparatively coarser texture and have other non-natural foreign substances (Jim, 1998b) as observed in Pedon 3. Pedon 2 had a coarse sandy loam texture in the 2BC and 2Cl horizons, which we expect was derived from outwash parent material. In general, Pedon 1 had a loamy soil texture, which is expected from less disturbed soils in this area (Lal and Ahmadi, 2000); some loess inclusion in the parent material for natural soils in this area is expected.

Electrical Conductivity

Anthropogenic factors such as the addition of salt to melt ice (Azovtseva and Smagin, 2018) could increase the concentration of salt in the soil, affecting soil health and productivity (Rengasamy, 2010). We observed relatively low concentrations of salts in the three pedons. This could be due to the location of the pedons not directly adjacent to a road or walkway and not receiving addition of salts during winter. A study by Shi et al. (2008), found that soils in an urban park had an EC average of 1.37 dS m⁻¹ and soils near roadside areas had an EC average of 1.15 dS m⁻¹ in urban soil located in Shenzhen City. Linde et al. (2001) reported EC measurements of 0.328 dS m⁻¹ in city center soils and 0.171 dS m⁻¹ in undisturbed soils in Stockholm, Sweden at the 0- to 5-cm depth. On average, soil EC observed in Pedon 1 was 0.161 dS m⁻¹, Pedon 2 was 0.170 dS m⁻¹, and Pedon 3 was 0.244 dS m⁻¹. Shukla and Lal (2005) reported EC values of 0.12 and 0.08 dS m⁻¹ for th 0- to 10- and 10- to 20-cm depth, respectively, in soils under no-till for 15 yr in an Alfisol in central Ohio.

Table 2. Total elements (mg kg⁻¹) for each soil horizon from three pedons.

<table>
<thead>
<tr>
<th>Pedon</th>
<th>Horizon</th>
<th>Depth</th>
<th>Al</th>
<th>As</th>
<th>Ca</th>
<th>Cd</th>
<th>Cu</th>
<th>Fe</th>
<th>K</th>
<th>Mg</th>
<th>Mn</th>
<th>P</th>
<th>Pb</th>
<th>Zn</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>*Ap1</td>
<td>0–10</td>
<td>5841</td>
<td>20</td>
<td>5,820</td>
<td>6</td>
<td>35</td>
<td>29,044</td>
<td>18,445</td>
<td>&lt;1460</td>
<td>721</td>
<td>912</td>
<td>146</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>*Ap2</td>
<td>10–22</td>
<td>6407</td>
<td>19</td>
<td>13,393</td>
<td>10</td>
<td>42</td>
<td>28,892</td>
<td>17,807</td>
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Total Carbon and Nitrogen, Soil Organic Carbon and Permanganate Oxidizable Carbon, Inorganic Carbon, and pH

Pataki et al. (2006) reviewed the concept of urban areas as whole ecosystems with respect to C balance. They found that after the natural ecosystem has been converted to an urban environment, organic C can be built up again in areas with managed vegetation–soil systems. Similarly, Poutay et al. (2006) found in a study comparing SOC in six major cities in the United States, that soils in urban environments have the potential to sequester large amounts of SOC, particularly if these soils are under a regime of high management inputs and minimal disturbance, for example turf grass in residential areas. We observed a TC decrease with depth in Pedons 1 and 3. Total N decreased with depth in all three pedons. Similarly, this behavior has been observed in other urban soils (Raciti et al., 2011) and natural soils (Wang et al., 2010). We suggest that the decrease of TC and TN with depth is due to the decrease of organic matter and root biomass at deeper depth. However, a different pattern was observed in Pedon 2, where TC decreased with depth until 68 cm, where TC increased due to the higher concentration of inorganic C. Pedon 1, classified as the soil series Celina silt loam (fine, mixed, active, mesic Aquic Hapludalfs), followed the same trend as a typical Celina profile for TC, a soil formed on glacial till of Wisconsinan age, perhaps with less influence at the surface (National Cooperative Soil Survey, 2018). Pedon 2 was mapped as a Celina map unit; however, the soil properties we observed and measured are better aligned with the characteristics of Eldean series (fine, mixed, superactive, mesic Typic Hapludalfs) (National Cooperative Soil Survey, 2018), a soil formed from glacial outwash. Comparing Pedon 2 with the Eldean soil series survey data, we observed a similar pattern where TC increases at the 2BC horizon (National Cooperative Soil Survey, 2018), collocated with significant content of rock fragments. Total C decreases in the deepest horizon, and that layer’s characteristics suggest a transition to glacial till at the base of the profile. Pedon 3 was originally mapped as an Eldean unit in the county survey. The profile of TC is consistent with our expectations of Eldean series, though other characteristics suggest that only the base of this profile is derived from natural soil weathering of glacial outwash. Approximately all the C on Pedon 1 was OC. In Pedon 2 more than 90% of the TC is SOC in the surface horizons, until the 2BC horizon is reached, where the majority is inorganic C, with <27% being SOC. This high concentration of inorganic C in the 2BC horizon is due to the outwash parent material for the central part of the profile. Although Pedon 1 showed a comparable amount of calcite and dolomite, the inorganic C fractions of Pedons 2 and 3 were dominated by dolomite. The greatest amount of inorganic C was found in the surface horizon of Pedon 3, and the 2BC and 2C1 horizons of Pedon 2. Dolomite, which is slightly harder and less reactive than calcite (Loeppert and Suarez, 1996), was found in higher concentrations where coarse fragments were also observed. We noted a strong correlation between dolomite and the total sand particle-size (coefficient of 0.711), mostly with the very coarse and coarse fractions. There was also a moderate negative correlation between dolomite and the fine silt and clay fractions (~0.510 and ~0.584, respectively). This suggests that the finer, more weathered fractions are composed more of non-dolomitic minerals.

In Pedon 1, pH and inorganic C increase from the surface into the *Ap2 horizon. This, and the presence of some asphalt fragments, is evidence of some surface incorporation of recent human transported materials. Although this site appears to be relatively less disturbed and has not been occupied by a building, the surface horizons may have been influenced by the recent demolition of an adjacent building (Vivian Hall).

All three pedons were under turfgrass cover; however, Pedon 3 also had surrounding trees. We found a high number of roots and crushed asphalt in the upper horizons of Pedon 3. The presence of both roots and asphalt could explain the high concentration of TC on Pedon 3 compared with the other two pedons, especially in the *AC horizon. Asphalt contains approximately 80% C (Freemantle, 1999). The TC and SOC spike observed in Pedon 3 in the *AC horizon was not associated with increases in POXC. This suggests that this SOC is not derived from natural biological organic matter but from the asphalt. Wang et al. (2010) found that SOC decreased with depth, but inorganic C does not necessarily follow the same trend. They studied the vertical distribution of soil inorganic and organic C under different natural landscapes. In Ohio, inorganic C levels increase below the solum in many soils with depth where parent materials are calcareous (such as limestone-derived glacial deposits). Solum inorganic C levels in Ohio soils are generally low due to leaching associated with udic moisture conditions through the Holocene. An increase in pH and inorganic C was observed in Pedon 2 in the 2BC, 2C1 horizons with a decrease in inorganic C for the 3C2 horizon. These results are consistent with calcareous glacial outwash parent material transitioning into glacial till at the base of the profile, and a positive correlation of soil inorganic C and soil pH (Yu et al., 2014). Permanganate oxidizable C has been used by researchers as an indicator of changes in the soil ecosystem (Culman et al., 2012). Generally, we observed a decrease in POXC with respect to the top layer concentration. This pattern is due to the labile portion of soil C being associated with the more biologically active layers (Culman et al., 2012; Weil et al., 2003).

Metals

Ratios of resilient/immobile minerals have been used to determine homogeneity of the parent material (Chittleborough and Oades, 1980). A combination of ratios was used to determine the homogeneity of the parent material since Ti is not as a stable as previously thought (Chittleborough et al., 1984; Marsan et al., 1988). The ratios of YO/ZrO2, ZrO/TiO2, and (YO2 × 10−2)/TiO2 were used to assess the distribution and homogeneity of soil constituents (Fig. 13).

Pedon 1 had consistent ratios throughout the soil profile, which suggests a homogenous parent material (Evans and Adams, 1975). The spike observed in Pedon 2 on the *BA to 2Bt horizons from Y appears to be related to a discontinuity from a heterogenous parent material. The spike observed is in the transition of the *BA to the 2Bt horizons. The Zr ratio spike on the fourth horizon also indicates a parent material heterogeneity. This horizon is different from the material above and under it.

The As measured from all the samples was higher than the State of Ohio Voluntary Action Program screening standard of 6.7 mg kg⁻¹. Arsenic concentrations in most horizons from the three pedons were >20 mg kg⁻¹. Venteris et al. (2014) analyzed baseline levels of soil As in Ohio. They found that high levels of As, >20 mg kg⁻¹, were not uncommon in Ohio, especially in the central and west central portions of the state. Observed Pb levels on
Pedons 1 and 2 were below the 400 mg kg\(^{-1}\) USEPA Pb screening level for residential soils. However, >400 mg kg\(^{-1}\) Pb levels were measured in horizon AC of Pedon 3 with the horizons above and below also having elevated concentrations of Pb. These high lead levels could be a result of the addition of a foreign material, since the lower three horizons have Pb levels similar to the other pedons.

Soil pH has a direct effect on the availability of essential nutrients for plant growth. The pH levels in the top 60 cm in all three pedons were not high enough to affect availability of essential nutrients (Table 2), with the exception of Fe. Soil pH levels of >7 can potentially fix Fe to soil surfaces, making it unavailable for plant uptake.

**CONCLUSION**

Urban soils can be highly disturbed soils that have been under the direct influence of human impacts. However, due to this anthropogenic activity, the processes and role of these soils in providing ecosystem services is not well understood. We used historic maps to locate three minimally disturbed soils in the study area. Soil characterization provided evidence of disturbance that has changed all three profiles since the development of The Ohio State University campus in the 19th century. Our study determined that Pedon 1 exhibited the least disturbance, mostly confined to recent additions of material near the surface. Pedon three was the most disturbed, with evidence that the surface horizons consist of human transported materials, with artificial inclusions such as asphalt. Soil data provided evidence of distinct parent material for all three profiles. Pedon 1 was formed mostly in glacial till. Pedon 2 was formed in a thin layer of glacial outwash over glacial till at the edge of a terrace of the Olentangy River. Pedon 3, located on a lower terrace also has significantly disturbed materials overlying the trunk of a glacial outwash-derived soil.

Due to the level of disturbance of the three pedons, we observed an Anthroposequence, where a series of profiles exists under different stages of disruption caused by human impact. Two locations were minimally disturbed (classified as phenoforms of Celina and Eldean soil series), whereas the third location has been subjected to major human disturbance. Due to the presence of human-transported material and asphalt, Pedon 3 had a higher concentration of C compared with the other more natural pedons. Pedon 3 may have initially been an Eldean series, having similar characteristics to Pedon 2, but the presence of foreign material highlights the significant difference in soil properties and function of a highly disturbed urban soil. Current work is focusing on using these minimally disturbed soils as a baseline for future urban soil mapping and characterization. This data will be used to determine changes on soil properties in urban ecosystems due to intensive management.

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**REFERENCES**


