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The effects of landscape cover on surface soils in a low density residential neighborhood in Baltimore, Maryland

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Abstract Previous studies at the scale of a city have shown that surface soil nutrients, pH, and soil organic matter (SOM) can vary by land cover, land use, and management. This study was conducted in Baltimore County, Maryland, to quantify the differences in characteristics of soil in a residential neighborhood and adjacent forest patch sampling at a fine scale. The first objective was to compare soil characteristics in a residential neighborhood among ecotope types of forest, lawn, and planting beds that were underlain by the same parent material and thus only differed in plant cover. Another objective was to examine differences in soil properties of lawn soils that differed in age by 10 years. The final objective was to quantify the variation of these residential and forest soils. Composite soil samples from the surface to a depth of 5 cm were taken from planting beds and lawns from 50 residences and an adjacent forest patch. Results showed that the forest soil had 30 % more SOM and was more acidic than lawn soil. Conversely, Mg, P, K, and Ca were 47 to 67 % lower in forest compared to lawn soils even though both soils developed from similar parent materials. For the residential lawns, the older development had significantly higher concentration of soil P. There was also a difference between front and back lawns where front lawns had 26 and 10 % higher concentrations of Ca and Mg, respectively, and a higher pH than the back lawns. Finally, the variation of soil characteristics of all areas sampled, from lowest to highest was pH < SOM < K < Mg < Ca < P. Results of this study suggest that anthropogenic factors appear to overwhelm natural soil forming factors in suburban residential areas in the Baltimore metropolitan area and these differences appear to increase with time.

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Introduction

Humans manipulate soils through land use and land cover transformations, which affect biogeochemical and ecosystem processes (Foley et al. 2005). One of these conversions is to turfgrass, which cover approximately 128,000 km^2 in the United States (Milesi et al. 2005). It is uncertain how these land-use conversions affect soil ecosystem and biogeochemical processes. An important question in urban soil research is the relative dominance of human- versus natural-soil forming processes and factors (Pouyat et al. 2008). A distinction between the two is that human induced disturbance and inputs can influence soils on time scales of much shorter duration than natural soil forming processes (Pavao-Zuckerman 2008; Pouyat and Effland 1999). In urban landscapes, especially in residential areas, management of soil typically occurs after the native soil has been disturbed by construction activities to maintain lawn cover and other cultivated plant cover types.

Horticultural and lawn management typically includes the addition of fertilizers, soil organic matter (SOM), lime, pesticides, and water to maximize the vigor of horticultural plant and turfgrass species (Cook et al. 2012). Observations of urban soil properties at the scale of a metropolitan area suggest that these management activities may result in relatively high rates of C accumulation (Golubiewski 2006; Gough and Elliott 2012), high alkalinity (Bloemen et al. 1995), and accumulation of nutrients such as P (Bennett 2003), calcium (Ca), and potassium (K) (Pouyat et al. 2007b) when compared to the native soils in the region.

As a contribution of the Baltimore Ecosystem Study (BES), a Long Term Ecological Research (LTER) Site (www.beslter.org) funded by the National Science Foundation, an eddy-flux tower was established to study carbon and energy fluxes of an urbanized landscape in a residential area of low- to medium-housing density. The study area for this research is centered within the meteorological footprint of the eddy-flux tower; the immediate area includes both residential and forested areas. Meteorological measurements of land-cover influences on below-canopy temperature have been made to integrate with those measurements made on the tower (Heisler et al. 2006, 2007).

A high resolution delineation of various "ecotopes" was also accomplished in a 1 km^2 footprint of the tower (Ellis et al. 2006). Our study used the same approach but at a finer scale. Ecotopes are ecologically distinct and homogenous units within landscapes (Ellis et al. 2000; Klijn and de Haes 1994). The basic ecosystem factors we used for classification were vegetation and ground cover, topography, and parcel (ownership) boundaries. Since there were different vegetation and ground covers in the residential study area, the occurrence of active management is implied, otherwise, plant succession would occur. The ecotope delineations allowed for comparisons of soil characteristics among front and back lawns, areas that were left unmanaged, horticultural beds within the residential areas, and forest. These delineated ecotopes represent different vegetation and ground covers, such as, the leaf and woody debris of the forest, the leaf/woody debris or grass cover of the unmanaged area, the turfgrass cover of lawns, and the mulch covers of the unraised and raised beds. Therefore, a comparison was possible between the delineated ecotopes of a largely managed landscape and a native soil of a forest patch, which served as a "reference".

Variability of soil characteristics affects ecosystem structure and function, carbon sequestration, and nutrient retention and cycling (Pouyat et al. 2007a). Moreover, the soils of the lawn ecotopes may reflect the evenness of management effects and prior disturbances and thus "homogenize", or lower the variability, of soil properties relative to the reference or native soils.

There were three objectives addressed by this study: 1) assess anthropogenic effects versus natural soil forming factors on soil properties by comparing ecotopes which reflect differences in plant and ground cover, management, and land-use history; 2) examine differences in soil properties of lawn soils in two subdivisions developed in 1970 and 1980 that varied in age by 10 years, and 3) compare the variation of soil properties for each ecotope.

With respect to the first objective, we expected differences in SOM between the soils of forest and lawn ecotopes due to SOM loss from site excavation and physical disturbances during the initial construction of each subdivision. With respect to the second objective, we expected the older lawn soil to have a greater accumulation of P, K, and SOM in the surface soil (0–5 cm) due to additions of "complete" fertilizer (NPK) and irrigation. Finally, the forest soil should exhibit greater variability in soil property measurements than the lawn soils due to topographic differences and variations in tree species.

Methods

Study area

The Cub Hill neighborhood was chosen as a study site because of existing studies in the area to measure long-term ecological effects focused on the atmosphere, soils, hydrology, vegetation, built environment, and soil organisms (Heisler et al. 2007; Pickett et al. 2008) (Fig. 1). The intent of these studies was to examine the influence of land use and cover and urban environmental factors on landscape characteristics and dynamics in a suburban ecosystem. Cub Hill is located in a low- to medium-density residential area in Baltimore County, Maryland, about 3 km outside the northeastern section of the Baltimore Beltway.

Cub Hill is located in the Mid-Atlantic Piedmont and is underlain by the Croom gravelly sandy loam, Croom-urban land complex, and a small inclusion of Beltsville-urban land complex (NRCS 2015). The soils are loamy-skeletal, siliceous, semiactive, mesic Typic Hapludults, which consists of very deep, well-drained to somewhat excessively drained, moderately rapid permeable soils on uplands. They formed in Coastal Plain deposits of sands and gravels. Slopes range from 0 to 15 %. Mean annual temperature is 15 °C and mean annual precipitation is 114 cm (Baltimore County 2011).

Sampling design

The experimental design explored the following comparisons of surface soil characteristics: 1) forest patch and residential subdivisions, with the forest soil representing natural soil formation and residential soils representing anthropogenic-influenced soil formation; 2) adjacent housing subdivisions built 10 years apart, 1970 and 1980, to investigate the effect of time on soil characteristics; and 3) yard patches that differ in their vegetation and ground cover and assumed landscape management (lawn, raised mulch, unraised bed, and unmanaged area). Areas were delineated into homogeneous ecotopes determined by attributes that we thought would have an effect on soil properties and characteristics, e.g., vegetation and ground cover, parcel boundaries, and topography (Fig. 1). Other factors affecting soil properties are previous grading of original native soil, mixing of various soil horizons, removal of organic layers, and

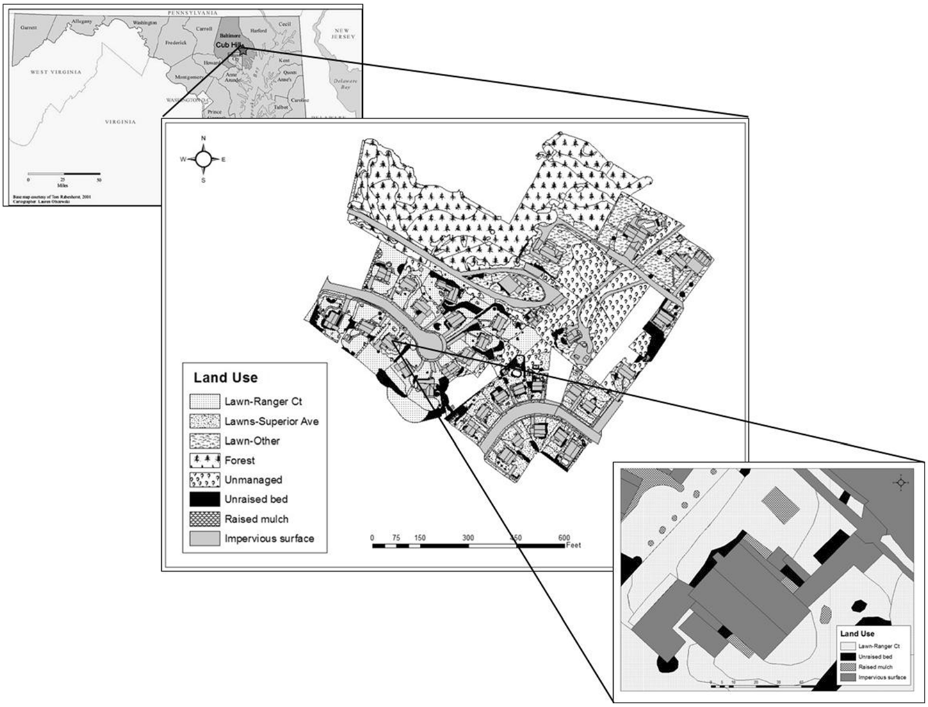

Fig. 1 Location of Cub Hill neighborhood within Baltimore County, Maryland, USA, and map of land-use classifications showing an enlarged view of an individual parcel

possible importation of soil from another location. Actual management survey data was not collected so management regimes are surmised given vegetation and ground cover types, e.g., forest includes ground cover of branches and leaves which suggests the absence of management, whereas a raised mulch bed suggests the presence of management such as weeding and the inputs of mulch.

At least ten composite soil samples from the surface to a depth of 5 cm were taken from each delineated ecotope. The sampled locations within an ecotope were equally spaced throughout the designated area and were taken with a stainless steel probe. A total of 598 composite samples from 598 delineated ecotopes were taken from June to August 2002 from all soil types and measured for pH, SOM, and the nutrients P, K, Mg, and Ca. The nutrients were extracted using the Mehlich-1 method (Mehlich 1953) at the University of Maryland-College Park Cooperative Extension Soil Laboratory.

The secondary-growth forest patch after agriculture was a 1.7 ha, closed canopy woodland at least 80 years in age (Fig. 2a) (57 samples). The forest consisted of mostly oak with planted pines along one edge of the area. The other edges were surrounded by roads and residential housing. The duff layer measurement was taken between the soil and the top litter layer, which had a range of thickness from 0 to 17 cm with a weighted average of 7.2±0.56 cm (57 measurements). The 'forest' soil (F) was sampled based on ecotopes that were delineated using topography, and vegetation and ground cover. 'Lawn' (L) was an area of a residential parcel characterized by turfgrass vegetation and thatch cover that was frequently mowed by the homeowner (Fig. 2b) (244 samples from 32 households); 'unraised bed' (UB) was a bed at ground level with vegetation cover made up of cultivated plants and a ground layer without

Fig. 2 Photos of land ecotopes: **a** Forest (F) ecotope. The forest consisted of mostly oak with planted pines along one edge of the area. **b** Lawn (L) ecotope. Lawns were an area of a residential parcel characterized by turfgrass that was frequently mowed by the homeowner. **c** Unraised bed (UB) ecotope. Unraised bed was a bed at ground level and an area of a residential parcel that was at least somewhat maintained by the homeowner, but was not actively mulched. **d** Raised mulch (RM) ecotope. Raised mulch was a landscaped area of a residential parcel that was actively maintained. **e** Unmanaged area (UM) ecotope. Unmanaged area was an area within a residential parcel not maintained in any way by the homeowner

mulch. Unraised beds were typically in an area of a residential parcel that was at least somewhat maintained by the homeowner but was not actively mulched (Fig. 2c) (171 samples from 31 households); 'raised mulch' (RM) was a landscaped area of a residential parcel that consisted of cultivated plants with an actively maintained mulch layer (Fig. 2d) (74 samples from 25 households); and 'unmanaged area' (UM) is typically made up of small tree or saplings, shrub cover, or vines with a ground layer of organic debris, shallow duff layer, herbaceous plants or bare soil. These ecotopes occurred within a residential parcel that did not show any evidence of active management by the homeowner, e.g., not mowed or mulched, but was previously disturbed during construction of the subdivision (Fig. 2e) (52 samples from 16 households).

Six surveyors worked in pairs to collect samples. Each pair of surveyors determined where the delineation marks of the ecotopes were to be drawn on the aerial photographs. Ecotope delineations were checked for accuracy and precision by the lead scientist. Thus, this sample design and delineation of field ecotopes may be repeatable but delineation error was not determined. In previous mapping, Ellis et al. (2006) found a 16 % area error by a set of trained interpreters for the delineation of the ecotopes in the Cub Hill 1 km^2 area, which was the sum of errors in ecotope area estimates as a percent of site area.

Principal Component Analysis (PCA) was used as a data reduction tool to explain variability and to visualize the comparison of plots spatially using SAS Proc FACTOR. The number of variables were determined using the eigenvalue for a given principal component. For the statistical comparisons, we defined class variables representing the soil forming factors such as topography (for forest) and age (two subdivisions). Area-weighted soil properties by age (35 vs. 25 years) and by cover were analyzed using the restricted likelihood estimation technique SAS Proc MIXED and GT2 Hochbergs pair-wise comparisons. The fixed effects were the ecotopes and there were no random effects. To compare the variability within each ecotope type, measures of variability were calculated for individual ecotope types using coefficients of variation (CV). Spearman correlations were used to determine relationships between certain variables such as topography and soil characteristics. The inference level of this research is the study area since neighborhoods and the forest ecotope were not replicated.

Results and discussion

Assessing anthropogenic effects on soil: Nutrients and pH

A principal component analysis revealed that pH, Mg, Ca, and K explained 61 % (Table 1) of the variability of the dataset (PC1 in Fig. 3). Similarly, a mixed model was significant ($P<0.001$) between F and L for PC1 (pH, Mg, Ca, and K) (Fig. 4). The F, L, and bed types were compared because of their inherent difference in vegetation and ground cover; F was

Table 1 Area-weighted eigenanalysis of the correlation matrix for SOM, pH, Ca, Mg, P, and K

Component	Eigen value	Variation explained (%)	Cumulative variation (%)
1	3.6	61	61
2	1.0	17	78
3	0.81	12	90
Variable	1	2	3
pH	**0.94**	−0.15	0.055
SOM	−0.34	**0.81**	0.47
Ca	**0.95**	0.027	0.19
P	0.42	0.56	**−0.72**
Mg	**0.92**	0.065	0.17
K	**0.85**	0.11	0.092

The bold values are those variables that represent each component

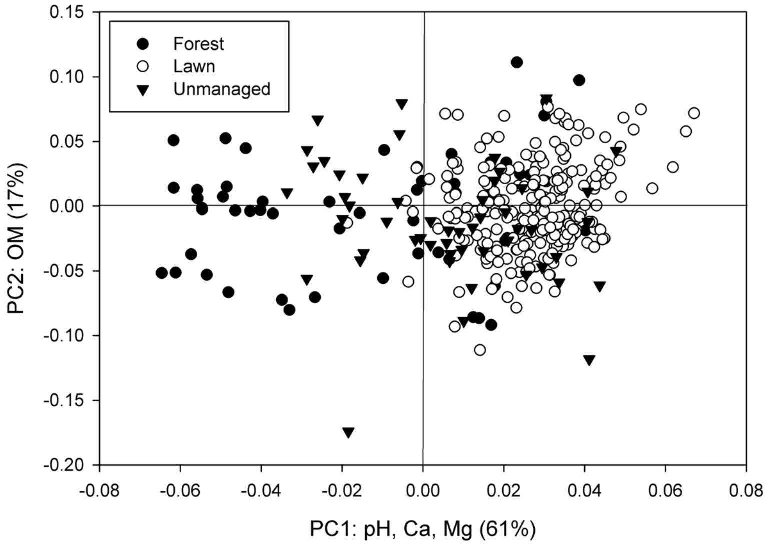

Fig. 3 Scatterplot of PC1 (pH, Ca, Mg, K) vs. PC2 (SOM) for F, L, and UM soils using all the plots. (All ecotopes were used for the PCA statistical run; however, UB and RM are not shown to simplify this figure)

considered representative of the native soil, not managed or disturbed, while the other ecotopes were viewed as having managed and disturbed soil, either from the initial housing construction or from subsequent use such as trampling. These PCA results support our hypothesis that F would contain lower concentrations of cations such as Mg, Ca, and K, and a lower pH than managed soils. An explanation may be that natural soil formation processes including leaching has taken place for a century in the F along with no addition of nutrients except those from atmospheric deposition. In the southeastern U.S., forest soils tend to be Ultisols which are generally acidic mainly due to the leaching of nutrients, such as base cations (Buol et al. 1989).

These same results could be interpreted from the management perspective: residential soils and beds have higher pH and higher concentration of nutrients than native F because of inputs of base cations, which overwhelm the natural effect of acidification and leaching. There were incremental step-wise increases of the cations P, Ca, Mg, and pH of 491, 471, 279 % and 1.8 pH units, respectively, from F, to UM, to L soil, to UB, and ending with RM (Fig. 4). However, this response was less evident for K and SOM. For example, L soil had the lowest percentage of SOM, 7.4 %, which was 30 % lower than SOM found in F. In contrast, L soils had the highest concentration of K, 166 mg kg^{-1}, compared to all other ecotopes, 14 % higher than RM, 146±6.9 mg kg^{-1}. Soils of UB and RM areas had high values of Mg (149±4.7 and 192±10.0 mg kg^{-1}), P (111±12.5 and 160±21.9 mg kg^{-1}), Ca (2132±90.2 and 3394±154.4 mg kg^{-1}), and pH (5.9±0.05 and 6.4±0.06), respectively. As expected, the two vegetation and ground cover categories that contained the highest nutrient values, RM and UB, were also the ecotopes that typically receive the largest amounts of inputs such as mulch or fertilizers. These beds typically incorporate the import of foreign topsoil and mulch which have an impact on the overall balance of soil nutrients. They could be perceived as “hot spots” (McClain et al. 2003) for C and nutrient accumulation. Lawn soils, compared to F soils, had higher concentrations of all cations and higher alkalinity but lower SOM. Only a few studies have investigated the differences in soil characteristics among ground cover at the resolution of a city (tens of kms), including remnant forest and residential lawn soils. In these studies,

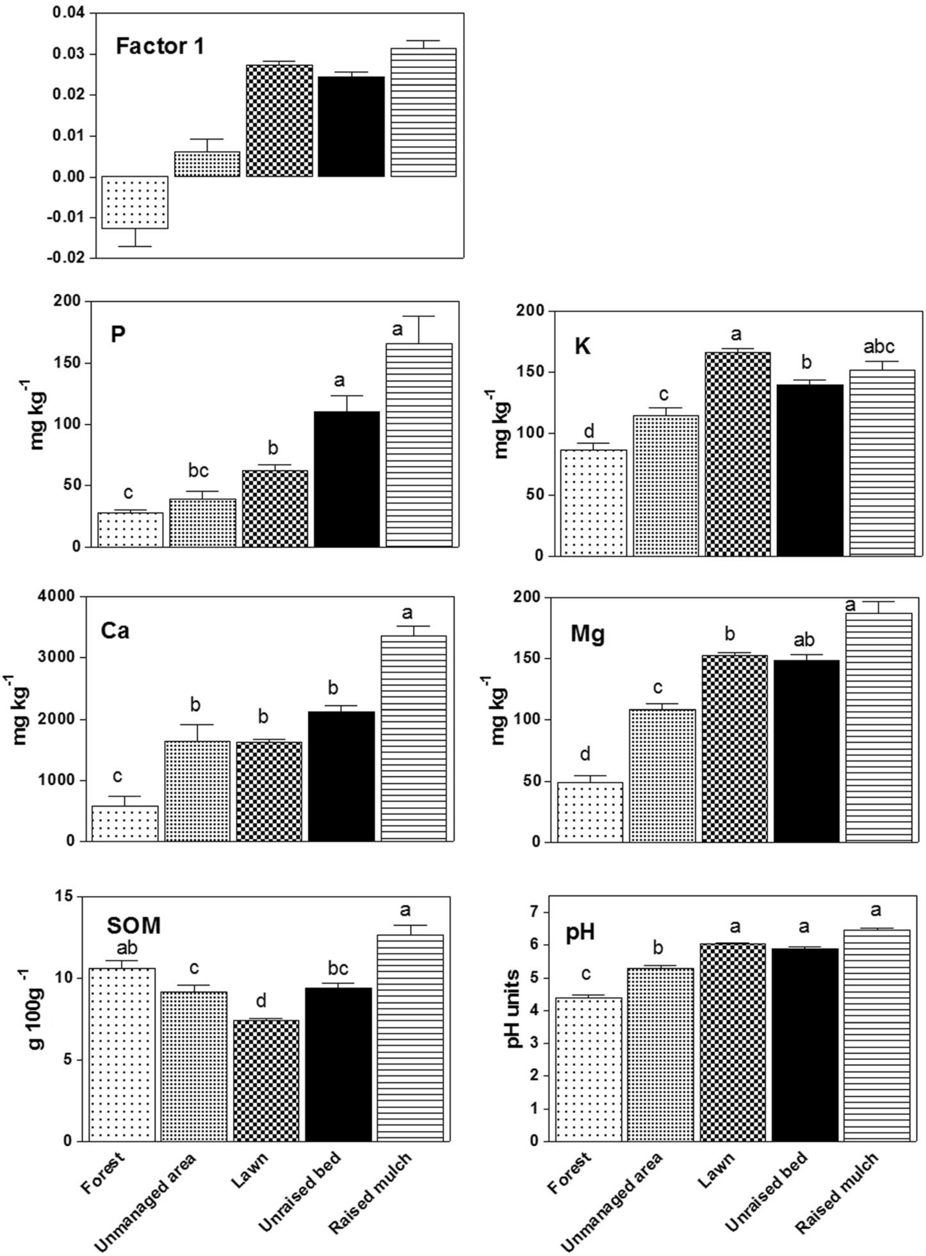

Fig. 4 The area-weighted mean (S.E.) soil nutrient concentrations, SOM and pH by land-use type. L (n=244), F (n=57), UB (n=171), RM (n=74), and UM (n=52). *Means with different letters* were significant at the 0.05 probability level

differences between forest and lawn, such as increased concentrations of P and K, higher bulk densities and enhanced soil C storage for residential lawns may have been related to management (Pouyat et al. 2007b). By contrast, for a coastal subtropical region there were no statistical differences between forest and residential soils for P, K, and SOM in Tampa, Florida (Hagan et al. 2012).

For context, we have attempted to find comparable ranges for the soil properties measured in our study. Recommended available soil concentrations (mg kg^{-1}) for horticultural soils are 300 to 1000 for Ca, 74 to 150 for K, 100 to 500 for Mg, and 30 to 60 for P (Whitcomb 1987) for a furrow slice of soil. Scotts Miracle-Gro Company suggests ranges for soil concentrations of 20 to 40 mg kg^{-1} for P, 150 to 250 for K, 6 to 7.5 for pH, and 3 to 6 % for SOM for healthy turfgrass establishment for the top 8 to 10 cm of soil (personal communication with The Scotts Company and Subsidiaries Consumer Response Representative, levels for Ca and Mg were not available). For this study, the levels (unweighted medians) in the L soils were 49 mg kg^{-1} for P, 158 for K, 6.2 for pH, and 7.2 % for SOM. All the nutrients, except for Ca, fall within the acceptable available soil concentration range for either horticultural or lawn establishment and therefore are not a limiting factor for lawn establishment. The SOM was slightly above the upper range, which may reflect the discrepancy between the depth of sampling and the recommendation soil sampling depth. The concentration of Ca found in L soils is 63 % higher than the upper range suggested for horticultural soils. For Baltimore City soils, high concentrations of available Ca (1350 mg kg^{-1}, median, n=122) may reflect urban dust; residential lawn soils contained 1305 mg kg^{-1} (n=52) (Pouyat et al. 2007b).

Soil organic matter

SOM was associated with the second PC, which explained 17 % of the data variability (Table 1 and Fig. 3). Forest soil had 30 % higher SOM concentrations than L, 10.6 compared to 7.4 % ($p<0.05$), respectively, in the 0–5 cm of the surface soil. The higher SOM in F was accompanied by a lower pH of 4.38±0.11 compared to L, 6.04±0.04 ($p<0.05$) (Fig. 4). To compare our values to other studies, we assumed a bulk density of 1.3 g cm^{-3} and an SOM conversion factor of 0.58 to estimate Mg of C ha^{-1}. It was estimated that F contained 40 Mg C ha^{-1}, with a range of 34 to 47 given bulk density ranges of 1.1 to 1.5 mg cm^{-3}; and, for L, 28 Mg C ha^{-1}, with a range from 24 to 32. The SOM values are comparable to eastern deciduous mixed forest soils for a loamy-skeletal, mixed, mesic Typic Dystrochrept in Erie, PA, and a coarse-silty, mixed, mesic Typic Dystrochrept in Big Flats, NY at 0–5 cm of total soil organic carbon of 42.61±2.44 and 48.48±3.74 Mg C ha^{-1} respectively (Corre et al. 1999); the same study sampled C_3 grass soils and found concentrations of 28.77±1.52 for Erie, PA, and 35.16±2.06 Mg C ha^{-1} for Big Flats, NY. The soils for Erie, PA are within the range of our study however the soils for Big Flats, NY are approximately 3 and 9 % higher in forest and grass soils, respectively.

Aside from vegetation and ground cover, there are natural physical features such as topography that can affect soil chemical properties. For F soils, topographic slope weakly correlated with SOM (r=−0.23), pH (r=−0.33), Ca (r=−0.37), Mg (r=−0.33), and K (r=−0.25) (data not shown). However, SOM was weakly correlated to topographic position and thus the typical relationship of decreasing SOM accumulation from toeslope, to summit, and to backslope was generally lacking. In the forest patch, the summit slope position contained the highest SOM percentage (12±1.1, n=16), followed by backslope (10±1.0, n=6), then toeslope (8.9±1.0, n=7). There was a slight relationship between duff depth and SOM in the F (r=0.21).

A possible explanation for SOM variability in the forest patch could be attributed to fine scale disturbances. For example, soils near the road were highly variable. However, moving toward the middle of the forest patch, the variability lessens. Furthermore, in the northeast corner of the forest, there was a vegetation discontinuity (mostly vines) that contributes to the high variability of SOM. Thus, topographic slope, duff depth, and disturbance can potentially explain some variability in SOM.

Not only did SOM exhibit relatively high variability under forest cover, there was also SOM variability within the UB and RM ecotopes that had differences in plant structural composition. For example, those beds that contained a tree (n=84) had the highest SOM percentages, 11.0±0.45 %, followed by shrub (n=133) at 9.4±0.38 %, and then herb (n=115), 8.7±0.97 %, and the lowest concentrations were beds dominated by weeds (n=95), 7.8±1.2 %. Homeowners may be adding more mulch around individual trees, while shrubs, which tend to have a higher branch density lower on the stems than trees, have less room under the shrub for homeowners to add mulch. The beds with herbs and weeds, which are similar in SOM, have a vegetation structure that may restrict the amount of mulch that can be added or may imply neglect. Not surprisingly, there is a correlation of bed litter depth to mineral SOM concentration (r=0.30, p<0.0001). This relationship may also be further explained by differences in litter input such as whether leaves are removed or remain under trees and shrubs.

RM and F had the highest SOM content of all ecotopes (p<0.05), 13.1 and 10.6 %, respectively which would be considerably augmented if the soil organic horizons were accounted. Conversely, the lowest amount of SOM was found in L soils (p<0.05), which had 5.7 to 1.8 % less SOM than the other ecotopes.

The biggest assumed difference between F and L is the addition of nutrients through the use of complete fertilizers, and the potential for loss of SOM during the construction phase of the residential housing development. In a previous survey of residences in Cub Hill, which included a few residents of this study area, we determined from survey data that 49 % of the residents fertilized their lawns at an average of 65.7 kg N ha^{-1} $year^{-1}$ (n=11). In another survey of residences in the Baltimore region, it was estimated that 106.9±21.8 kg N ha^{-1} $year^{-1}$ was applied to residential lawns by homeowners (Law et al. 2004). In contrast to lawn management efforts, forest patches only receive nutrient inputs through atmospheric deposition and recycle nutrients through leaf drop and decomposition and thus a greater proportion of cations are incorporated into plant biomass than the other ecotopes.

Properties of lawn soils in subdivisions built 10 years apart

We compared soils of two different subdivisions to investigate the effect of age on soil characteristics of L soils. The two subdivisions differed in age by 10 years, which was a relatively brief time to measure the response of natural soil processes. However, for anthropogenic factors such as management, we expected measureable differences regardless of the relatively short time period for soil formation to occur. From the PCA, the third explanatory variable was related to P (Fig. 5) which explained 13 % of the variation of the dataset. As expected, there was two times more soil P (p<0.05) in the old subdivision (112±33 mg kg^{-1}) compared to the younger (50±8.0 mg kg^{-1}). However, there was no significant difference between the two subdivisions for K, Mg, Ca, pH, and SOM (Table 2).

In general, P does not leach from the soil profile easily due to its ability to bind to other cations and anions over a range of pH levels; therefore, the addition of fertilizer typical for lawn management has the potential to produce a measurable increase of soil P over a decade

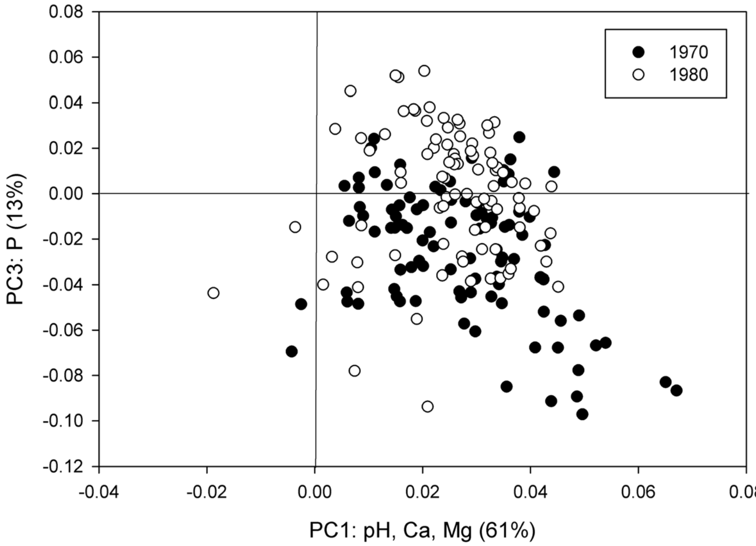

Fig. 5 Scatterplot of PC3 (negatively correlated P) vs. PC1 (pH, Ca, Mg, K) for L located in parcels built in 1970 and 1980. Each *dot* represents one L ecotope; each parcel could contain from 2 to 8 ecotopes. (All ecotopes were used for the PCA statistical run; however, only the L are shown to simplify this figure)

assuming no substantial P losses through erosion. Similar results were found in a study in Dane County, Wisconsin, where residential lawns contain higher mean soil P concentrations, 56 mg kg^{-1}, than their native prairie counterpart, 17 mg kg^{-1} (Bennett et al. 2005). If we assumed a common fertilization formulation of NPK to be 29-3-4, and an application rate of 65.7 (determined from local survey data) to 106.9 kg N ha^{-1} year^{-1} (Law et al. 2004), then P would be applied from 6.8 to 11.1 kg P ha^{-1} year^{-1}. Over 10 years, this rate would translate into a total addition of 68 to 111 kg of P ha^{-1}.

Another comparison of L soils was to determine if there were differences related to front and back L soils, even though our original study design did not include a comparison of front and back L soils. We expected there to be differences in management effort between front and back L soils based on social dynamics related to the homeowner's desire for an acceptable lawn appearance (Cook et al. 2012). Since the front lawn is viewed more by neighbors compared to the back lawn, it tends to be more manicured (Larson et al. 2009; Richards et al. 1984). Since a

Table 2 Soil variable area-weighted means (S.E.) for lawns by age of development

Variable	Age of development		*P* value
	1970 (*n*=12)	1980 (*n*=16)	
SOM (g 100 g^{-1})	7.9 (0.38)	7.3 (0.29)	0.23
pH	5.9 (0.13)	6.0 (0.11)	0.64
Ca (mg kg^{-1})	1548 (144)	1589 (120)	0.83
Mg (mg kg^{-1})	174 (18)	144 (4.2)	0.086
P (mg kg^{-1})	112 (33)	50 (8.0)	0.046
K (mg kg^{-1})	157 (5.9)	154 (7.9)	0.79

comprehensive survey was not conducted, we can only speculate about the cause of these differences. Consistent with our expectation, we found increased concentrations of Ca, Mg, and a higher pH in the front than in the back soils. Results show that front L soils have 26 % and 10 % higher concentrations of Ca and Mg than back soils, respectively. These results are also corroborated by a higher pH in the front L soils, 6.2, than the back, 5.7 (Table 3). Magnesium was highly correlated with calcium (r=0.53), which may be related to the relationship between calcium and magnesium in rock formations that are used to create lawn products, i.e., dolomite. Moreover, these relationships imply that residents are more likely to lime their front lawn compared to their back lawn. The literature does suggest that residents have different landscape choices for front and back yards (Larson et al. 2009).

Variability of soil characteristics

Our third objective was to quantify and compare the variability of the soil properties for each ecotope. To our knowledge no studies have examined the variability in soil properties at the scale of a suburban residential neighborhood. This information helps to better understand soil formation processes taking place in urban landscapes since broad application of supplements, use of monocultures, and other management efforts should cause a "homogenization" of measured characteristics at the parcel scale (Pouyat et al. 2007a).

As expected, F soil generally had the highest variation, measured by area-weighted CV among ecotopes for all soil properties, which we attribute to topography and natural variation (Table 4). For the F, Ca was the most variable and pH, the least variable. To provide context to our results, in a study investigating variability among forest soils of the Georgia Blue Ridge Mountains (Ike and Clutter 1968), the CV for exchangeable Mg (87) and K (47) were similar to our F soils, however, pH (6.7) and available P (46) were lower while exchangeable Ca (225) and organic matter (57) were higher.

Separating out the anthropogenic ecotopes such as lawn, raised mulch, unmanaged areas, and un-raised beds, P is the most variable. For all the variables measured in anthropogenic ecotopes, it was surprising to find a consistent order of variability. In other words, pH, SOM, K, Mg, Ca, and P generally decreased in variability from forest to unmanaged area, unraised bed, raised mulch, and lawn. Lawns, which had the lowest variability of all the soil properties,

Table 3 Soil variable area-weighted means (S.E.) for front and back lawns

Variable	Location of lawns		P value
	Front (n=24)	Back (n=24)	
SOM (g 100 g^{-1})	8.0 (0.33)	7.3 (0.22)	0.0637
pH	6.2 (0.08)	5.7 (0.10)	<0.0001
Ca (mg kg^{-1})	1814 (104)	1419 (130)	<0.0001
Mg (mg kg^{-1})	168 (11.3)	153 (7.9)	0.0026
P (mg kg^{-1})	82 (19)	77 (19)	0.8246
K (mg kg^{-1})	160 (6.3)	148 (6.6)	0.5608
PC1	0.0285	0.0164	0.0118

Table 4 Soil variable area-weighted coefficient of variation (CV) by ecotope

Ecotope	pH	SOM	K	Mg	Ca	P
Forest	18	36	44	88	195	64
Unmanaged area	14	35	36	33	118	121
Lawn	9	24	28	28	49	116
Un-raised bed	12	36	36	42	55	146
Raised mulch	9	42	41	44	39	117

may be explained by the tendency of homeowners to manage consistently across differently owned parcels at the scale of a neighborhood (Cook et al. 2012). RM had the second lowest variability for all the soil variables which may reflect the import of similar materials, such as mulches and garden soils, to these beds.

The order of CV for the nutrients was consistent with other studies regardless of management, land cover, and land uses used for the comparable studies. The order of increasing variability as measured by area-weighted CV was pH < SOM < K < Mg < Ca < P, which was the exact order found with data collected in another study within suburban areas of Baltimore County (R. Pouyat and I. Yesilonis, unpublished data). A similar order of variance was found in Baltimore City, pH < Mg < SOM < K < Ca < P, across several different land uses, such as institutional, industrial, residential, commercial lawn, and forest soil (Pouyat et al. 2007b).

These comparisons over different scales and soil types suggest there is a relative order of nutrient variability that is consistent at different scales regardless of management and land-use categories. Based on these results, a homeowner or landscape manager would need to sample more intensively for P and Ca to accurately characterize the mineral soil of the suburban neighborhood landscape, and less so for pH and SOM.

Summary and conclusion

This paper reports on comparisons of soil characteristics among ecotopes found in one forest patch and two subdivisions (L, UB, RM, and UM) containing 32 households that are located on similar soil types (Typic Hapludults). Because data on actual management inputs across the households was not available we can only speculate on the causes for the differences found among the ecotope types. However, our results from the comparison of residential neighborhood soils to a reference soil, subdivisions of different age, and front and back lawns suggest the importance of anthropogenic factors on soil properties. These anthropogenic factors, such as management and the manipulation of cover, appear to overcome natural soil forming factors through an increase of pH and nutrient concentrations of P, K, Ca, and Mg in the surface 0–5 cm. Future experimental designs of residential soil studies investigating anthropogenic effects should incorporate a native control patch, such as forest, prairie, or desert, as a standard of comparison.

There were greater concentrations of P in the older subdivision of lawn soils of two subdivisions that varied in age by 10 years, one developed in 1970 and 1980. Phosphorus may be an indication of how long and how intense a soil has been subject to management practices. Furthermore, we found L soils occurring in the front of residences appeared to be managed differently than L soils in the back as indicated by greater concentrations of Ca, Mg, and a higher pH in the front.

Finally, variability across the landscape was highest for P and Ca and lowest for pH and SOM, which was consistent with an earlier investigation of soils in Baltimore City and County. This information has important implications for developing experimental designs, mapping soils, and understanding soil nutrient retention and cycling in urban landscapes.

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