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Variations of Soil Organic Carbon in Three Urban Parks : A Maine Case Study

M.R. Banaitis,* S.J. Langley-Turnbaugh and A. Aboueissa*****

**University of Maine, 5722 Deering Hall, Orono, ME 04469-5722*
***University of Southern Maine, Department of Environmental Science,*
37 College Ave., Gorham, ME 04038,
****University of Southern Maine, Dept. of Mathematics and Statistics,*
96 Falmouth St., Portland, ME 04104-9300,
E-mail : Langley@usm.maine.edu

Abstract

The organic carbon content of soils is an important factor in the assessment of soil health. Soil organic matter (SOM) increases soil's ability to adsorb and transport essential plant nutrients; increases water holding capacity; and buffers against compaction. Increasing organic carbon levels in urban park soils, therefore, may result in soils requiring less maintenance, such as fertilization or seeding. The objective of this study was to assess variability of total organic carbon (TOC) in three urban parks in Portland, Maine, and to compare TOC levels in turf grass dominated areas of the park with soil properties and land use intensity. TOC levels varied between 40-50 g/kg, consistent with values found in other urban settings, and the park with the highest foot traffic volume had the lowest TOC values. There were no consistent significant relationships between the various soil properties and TOC, but there was a strong correlation between TOC and above ground biomass (R = 0.79) in one park. Thus, biomass left on-site through grounds management may represent the greatest potential to increase organic carbon in these urban park soils.

Keywords: organic carbon; soil organic matter; urban soils; urban greenspace, urban soil management; park management; greenspace management

Introduction

Soil organic matter (SOM) is a well known for its beneficial influence on soil properties and plant growth. Therefore, it is an important factor in the assessment of overall soil health and productivity. Studies have demonstrated that elevated amounts of SOM increase soil adsorption and transport of essential plant nutrients (Pulleman, 2000; Bauer, 1994), increase soil water holding capacity (Pulleman, 2000; Tester, 1990), and buffer against the effects of compaction (Tester, 1990; Bauer and Black, 1992). In disturbed urban soil-systems, however, the organic matter content, function, and properties differ from typical, undisturbed forest or agricultural systems (Beyer, 2001).

Limited information is available, however, on the dynamics of organic carbon in urban park soils, particularly those found in urban greenspace areas dominated by turf grass. Total organic carbon (TOC) is a relatively easy soil property to measure and can be related to SOM. Thus, we conducted an in-situ study to compare turf grass areas in three parks in Portland, Maine. Specifically, the objectives of this study, were to (1) characterize the soils in three urban parks; and to (2) test the hypothesis that there are significant differences between TOC in the three parks that are related to soil type and land use intensity.

Knowledge of these relationships will expand our understanding of the role organic carbon plays in urban park soils. This information may assist urban greenspace managers in selecting management practices that will maintain TOC in these soils. An understanding of specific practices that may foster changes in soil TOC levels will enable managers of these urban greenspace soils to modify practices, potentially maintaining overall soil health.

Site Description

Payson, Deering Oaks and Fort Allen are urban parks in Portland, Maine and were selected for this study based on the length of time they have been functioning as park areas. Payson Park is composed of 50 acres of open, grass lawns with a few young trees, playgrounds and playing fields. Payson once functioned as a tree and shrub nursery, but became a park in the early 1900s and is now heavily used for active recreation including baseball, soccer and field hockey. Payson is composed primarily of young red oak (Quercus rubra), American beech (Fagus grandifloria), white birch (Betula papyrifera) and white pine (Pinus strobus). All samples in this park were collected from turfgrass dominated areas.

Deering Oaks is 52 acres in size and features a large stand of mature trees, large stretches of grass lawn, and distinct areas for organized recreation. Deering Oaks is used heavily for casual recreation, a weekly farmer’s market, and several summer festivals and concerts. Deering Oaks was originally a farm, but was acquired by the city and turned into a park in 1879, and is on the National Register of Historic Places. There are 1,000 trees in Deering Oaks Park with predominant stands of Red and White Oak (Quercus rubra and alba) along with a mix of introduced exotics such as Yellowood (Cladrastis kentukea), Catalpa (Catalpa speciosa) and Horsechestnut (Æsculus hippocastanum). The park contains three trees on the State of Maine 'Big Tree' list including: Pin Oak (*Quercus palustris),* Siberian Elm (Ulmus pumila) and Yellowood. All samples in this park were collected from turfgrass dominated areas.

Fort Allen is 5 acres in size and originally served as an active fort, constructed to protect Portland Harbor. Most of Fort Allen was forested, then became pastureland prior to being acquired by the city. Fort Allen was acquired by the city and turned into a park in the 1880s, and includes a large, grass lawn dotted with mature trees. Fort Allen is very popular with the public, especially for firework displays and band concerts, but is less heavily used than either Payson or Deering Oaks. Fort Allen is composed primarily of softwoods, including Norway spruce (Picea abies) and red pine (Pinus resinosa) planted in 1920. All samples in this park were collected from turf grass dominated areas.

Annual precipitation in Portland is 116 cm and mean annual temp is 7.6^{o} C. Parent material in each of the parks consists largely of fill material, including multiple layers of material dredged from Portland Harbor. Dredged materials have been deposited randomly over time, but not since the late 1800s. Soil texture in the control section of each park is loamy, and Deering Oaks and Fort Allen parks are moderately well drained, while Payson Park is somewhat poorly drained due to a higher clay content. Surface horizons vary from dark gray (10YR 4/1) to very dark brown (10YR 2/2) and surface textures vary from sand to clay loam. Subsurface horizons vary from olive gray (5Y 5/2) to dark yellowish brown (10YR 4/4), and from loamy sand to clay loam. Slope varies from nearly level to moderately sloping in each park, but all samples were collected from similar topographic positions. A large fire burned a substantial portion of the Portland peninsula, where the three parks are located in 1866. Therefore, time zero for soil formation in the 3 parks is widely considered to be the late 1800s, and evidence of ash from the fire has been noted in soils pits in the 3 parks. All parks are managed the same – they are routinely mowed and clippings are removed, and leaves are mulched and removed in the fall. The parks are not irrigated, and receive no fertilizers. They are periodically aerated on the surface only to relieve compaction.

A study that inventoried human activity and degree of disturbance via formal direct observation determined that Payson Park is the most heavily used followed by Deering Oaks and Fort Allen, respectively (Payson Park>Deering Oaks>Fort Allen)(Langley-Turnbaugh and Evans, 2001).

Methods and Materials

Four transects, each 200 meters in length, and oriented perpendicular to topography were established in each park. Surface (A horizon, 0-10 cm) samples every 20 meters along the transects. Samples were collected from areas dominated by turf grass. Samples were air dried, ground, and passed through a 2mm sieve. The samples were analyzed for total organic carbon using a CE Elantech NC Sediment Analyzer.

Soil texture was determined using the hydrometer method (Gee and Bauder, 1986). Bulk density was measured by the core method (Soil Survey Laboratory Staff, 1992). Temperature was determined in-situ and soil moisture was determined gravimetrically (Soil Survey Laboratory Staff, 1992), then converted to volumetric percent for surface samples where bulk density values were available. Soil pH was determined using a standard glass electrode in 10:1 water solution (Soil Survey Laboratory Staff, 1992).

Aboveground biomass was determined by collecting clip harvests of turf grass within a known area from ten percent of the total sample sites. The samples were dried for three days (60°C) and weighed.

Due to non-normality within data, a nonparametric, Kruskal-Wallis method was used to compare the average surface and sub-surface TOC. Kruskal-Wallace was also used to compare averages of various soil properties (TOC, soil texture, temperature, moisture, pH, bulk density and aboveground biomass) between each park. Furthermore, Mann-Whitney was used to compare these averages between the three parks and within each park. Regression analysis techniques were used to examine relationships between TOC and soil texture, temperature, moisture, pH, bulk density and aboveground biomass. All significant differences or correlations are reported at the 95% confidence level ($p < 0.05$)

Results and Discussion

Overall, the data revealed that there was a significant difference between average TOC levels for the three parks over the three years of data (Table 1). Fort Allen had the highest TOC levels (49.2 g/kg) followed by Deering Oaks (44.4 g/kg) and Payson Park (41.0 g/kg).

In Maine, average organic carbon values in forest soils nearby the study area range from 80 to 450 g/kg in surface soils and 60 to 80 g/kg in sub-surface (Rourke, 1982). Typical values of soil carbon within non-disturbed, hardwood-forested systems of southern New England area averaged 250 g/kg in both the surface and sub-surface (Davis et al., 2004). Typical values for TOC in this study are markedly lower than these levels yet are similar to levels found in the soil of New York City's Central Park (39 g/kg) (Pouyat et al., 2003), as well as an urban park in Germany (51 g/kg) (Beyer, 2001). Organic carbon values in urban soils are variable, however. Short et al. (1986) found an average organic carbon content of 19.7 g/kg, ranging from 3.5 to 46.9 g/kg, in surface soils of the Mall in Washington D.C. and in a study of one of Hong Kong's urban parks TOC levels averaged 6 g/kg (Jim, 1998).

Table 1 : Descriptive Statistics for chemical and physical soil parameters for Deering Oaks, Payson, and Fort Allen Parks

Surface		TOC for all years g kg^{-1}	% clay	% sand	% silt	pH (10:1 H_2O)	Bulk Density g kg^{-1}	Aboveground Biomass g kg^{-1}
Deering Oaks n = 40	Average St. Dev.	44.4a† 12.3	23.3a 9.8	55.5a 16.4	21.2a 12.6	5.41 b 0.50	1.16 a 0.16	93.6 a 49.7 n = 12
Payson Park n = 38	Average St. Dev.	41.0b 18.5	31.1a 9.7	38.6a 13.2	30.2a 11.2	5.67 a 0.47	1.16 a 0.26	109.6 a 46.2 n = 12
Fort Allen n = 22	Average St. Dev.	49.2c 10.9	25.3a 6.6	51.5a 7.9	23.2a 6.2	5.53 a 0.38	1.13 a 0.16	121.3 a 61.9 n = 9

† Different lower-case letters denote significant spatial difference between parks; $p < 0.05$.

Using a previous ranking scheme based on formal observations of land use intensity (Langley-Turnbaugh and Evans, 2001), the most heavily used park (Payson) also had the lowest carbon values. From strictly a qualitative standpoint, if both land use intensity and TOC are evaluated according to their respective park, the park with the highest land use intensity had the lowest organic carbon values (Figure 1). This qualitative assessment indicates a relationship between land use intensity and TOC may exist within these three parks. However, future studies would need to specifically address land use intensity in more quantitative terms to detect such a relationship.

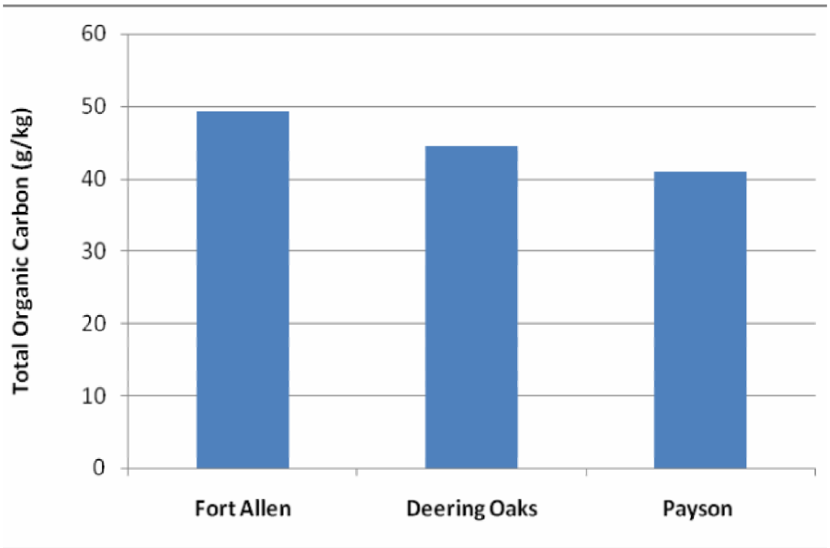

Figure 1 : Average Total Organic Carbon (TOC) within the Three Parks. Land use intensity increases from left to right (i.e. Fort Allen < Deering Oaks < Payson Park).

Relationships between TOC and various soil properties were not consistent over time or space. For example, particle size data from each park showed that the soils are texturally quite similar (Table 1). Thus, although texture often is a strong controlling factor on TOC within a climatic zone where temperature and precipitation are constant, the similarity in texture between sites negates this effect. Parent material is a dominant control over soil texture, especially in young, urban settings, thus it is likely that parent material used to construct these three parks is not a dominant control over total organic carbon.

Likewise, only weak significant relationships between TOC and temperature ($R < 0.34$) and soil moisture ($R < 0.61$) were found, and soil moisture was not correlated with texture. Moisture content in surface soils of the three urban parks generally fell within the range typically associated with the most plant available water (10-35%). Soil temperatures for the three urban parks were markedly higher than nearby rural soils, which averaged 9°C in forest soils and 10°C in agricultural soils (Hughes et al., 1993). However, it is important to note that soil moisture and temperature data should be interpreted with caution, as they are one time measurements and not continuous. An extensive study of temporal changes in soil moisture and temperature was beyond the scope of this study.

Limited data currently exist on soil temperatures within urban environments. Temperatures in urban soils are generally higher than rural, agricultural or forest settings, due to the increased heat storage capacity of urban settings commonly known as the urban heat island effect (Grimmond and Oakes, 1999; Craul, 1992; Landsberg, 1981). Increased temperature may lead to increased carbon decomposition, due to an increase in microbial respiration, potential evapotranspiration and biomass production (Brady and Weil, 2002), eventually leading to a depletion of soil organic carbon below levels found in typical, undisturbed systems. Thus, the relationship between precipitation, soil temperature, and soil moisture in an urban green space setting warrants further investigation.

Again, with bulk density results were not consistent over space or time. Yet, it is well known that an increase in carbon is expected to result in a decrease in bulk density. Deering Oaks and Payson Parks had the same average bulk density, 1.16 g/kg, Fort Allen had an average bulk density 0.96 g/kg (Table 1), and the bulk densities were not significantly different between the three parks. There was a significant weak (R = - 0.31) negative correlation between bulk density and TOC for Deering Oaks.

Compaction of urban soils, particularly in parks and greenspace, is common and expected due to the higher intensity of use such as foot traffic and maintenance equipment (Pouyat et al., 2003; Jim, 1998; Short et al., 1986). In a review of published urban soil characteristics, Craul (1985), found reported urban soil bulk densities often exceeded the high limit of bulk density found in natural soils, ranging from 1.34 to 2.18 g/cm^3. Individual studies of urban soils reported values that ranged from 1.17 to 2.16 g/cm^3 (Jim, 1998) and 1.25 to 2.03 g/cm^3 in loamy soils (Short et al., 1986). Bulk density in the present study was lower than these values, ranging from 0.96 to 1.16 g/cm^3, indicating less compaction had occurred on these sites compared to others studied. From a land use perspective, therefore, the soils in the present study showed relatively healthy bulk density values for urban park areas. Future research evaluating bulk density variability over time under varying degrees of land use intensity in urban green space areas would provide more insights.

The two park properties exhibiting the strongest relationship to organic carbon are pH and biomass. TOC and pH were negatively correlated in Payson Park (R = -0.61) and Deering Oaks (R = -0.40) surface samples during the three years of sampling, suggesting that soil acidity may be related to TOC in these two parks. A decrease in soil organic matter may result in a decrease in acid production, resulting in an increase in soil pH. The pH values in our urban soils ranged from 5.15 to 5.75, slightly higher than the average rural Maine pH values, which typically range from 4.6 to 5.0 (Rourke, 1982).

Typically, reported pH levels in urban soils are higher than natural soils systems of nearby, rural areas (Craul, 1992; Short et al., 1986; Jim, 1998; Beyer, 2001). Many hypothesized explanations for the elevated pH levels in urban soils have been presented over the years and include; increases in base cations, such as calcium and magnesium due to winter road salting activities in northern latitudes (Pham et al., 1978); presence of base cations due to decomposition of building rubble such as concrete and plaster used as components of fill material (Bockheim, 1974; Chinnow, 1975); and atmospheric deposition of ash from industrial/household wood burning activities, which contained 32% calcium (Zemlyanitskiy, 1962). Park soil amendments such as lime could explain the increase in the pH values of this study but historically no such management methods have been undertaken within these parks (Tarling, Personal Communication, 2006). However, Payson and Fort Allen are both ocean-side parks, so the elevated pH may be due to the input of marine aerosols. Collection and analysis of urban aerosolic dusts and precipitation over time may reveal an atmospheric mechanism where base cations are entering the soil environment, thus increasing pH to levels higher than nearby rural areas.

Finally, there was a strong, positive correlation between biomass and TOC ($R = 0.79$) within Deering Oaks samples from 2000, but no significant differences were found either over time or spatially between parks. Allocation of carbon from the atmosphere and subsequent storage in plant tissue is a well-known process in biogeochemical cycling. Indeed the amount of atmospheric carbon that is fixated within plants, as both aboveground and belowground biomass, directly affects rates of carbon input to soils (Jobbagy and Jackson, 2000). Therefore, measuring changes in biomass production over time should reveal a relationship with soil organic carbon. However, measuring both above and belowground biomass were beyond the scope of this study. Thus, aboveground biomass production was used as an indicator of organic carbon inputs. While consistent relationships amongst parks were not found, a strong, positive correlation between aboveground biomass and TOC within Deering Oaks Park indicates these comparisons may warrant future investigation, perhaps within other urban greenspace settings.

Furthermore, the City of Portland Parks Management Department has historically practiced removal of all surficial plant materials such as grass clippings, and leaf litter (Tarling, Personal Communication, 2006). This removal of organic matter breaks a major pathway of soil carbon input and will likely result in a net loss of total carbon entering these soils over time. Future investigations into the specific effects of management strategies (e.g. removal of grass clippings vs. non-removal) on TOC in urban soils would help determine if significant benefits result from allowing surface plant material to remain in place following maintenance. Retaining surficial biomass, such as grass clippings, would add to soil organic carbon, thus reducing compaction; increasing water holding capacity as well as cation exchange capacity.

Each of these benefits, due to increased TOC, would likely reduce the frequency of required soil maintenance operations, such as fertilization and watering, specifically within these three park systems. From an economic standpoint, the reduction in maintenance operation frequency in these parks would likely lead to a reduction in overall costs associated with maintenance.

Conclusions

There was a significant difference in TOC between the three parks. The qualitative assessment indicated a decrease in TOC with increasing land use intensity. It is not clear, however, how land use intensity affects the overall cycle of carbon in these three urban soil systems.

Furthermore, the evaluation of various soil properties and their relationship to TOC did not indicate any one soil property as a control over organic carbon, although the strongest relationships were between TOC and pH and TOC and biomass. Thus, while land-use intensity may affect carbon cycling, other factors not measures in this study, such as organic matter decay rates, which are very sensitive to changes in soil moisture and soil pH, may have the greatest influence on TOC in these urban soils. Inputs of carbon are predominately controlled through atmospheric fixation by plants and can generally be measured through biomass production, both above and belowground. Thus, changes in overall soil management, such as enhancing carbon inputs and net primary productivity through leaf or grass mulch, may represent the most influential control over TOC in these three urban soil systems.

Future research should focus on the effects of various management strategies on organic carbon in urban greenspace soils. Strategies such as retaining grass clippings following mowing operations and retaining shredded or mulched leaves may generate overall increases of long-term organic carbon content. Human populations will continue to grow in urban centers, presenting a continual increase in stress upon greenspace areas and the soils they rely on. Research in management methods that promote the greatest overall benefit to these soils will help reduce future detrimental impact that results directly from human influence or mismanagement.

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