Urban Soils in Gainesville, Florida, and Their Implications for Environmental Quality and Management[1]

Donald Hagan, Cynnamon Dobbs, Francisco Escobedo, Wayne Zipperer, and Zoltan Szantoi[2]

Urban planners, environmental scientists and land managers in Florida are increasingly aware of the ecosystem services provided by the trees and shrubs that comprise an urban forest (http://edis.ifas.ufl.edu/document_fr276, Escobedo *et al*. 2010). Yet soils, which form an essential part of the urban ecosystem and provide many important ecosystem services as well, remain largely overlooked (Hagan *et al*. 2010). Since many urban soils in Florida are highly modified and/or made of fill brought from elsewhere, it is frequently assumed that they are homogenous, heavily disturbed, or of low fertility. Soil survey maps or urban forest assessments do not even describe urban soils, delineating them instead as blank areas on the landscape or focusing solely on individual tree soil requirements (http://edis.ifas.ufl.edu/document_fr276). Recent studies, however, have found that urban soils are highly variable, ranging from highly modified to nearly undisturbed. Nonetheless, certain trends and patterns in urban soil characteristics have been observed (Pouyat *et al*. 2007). This publication will shed light on how and why soil properties vary across Gainesville and provide useful information on the sustainable management of urban soils. It is meant to complement the more general overview of Florida's urban soils given in Hagan *et al*. (2010).

Gainesville provides a good example of how soils in north central Florida are affected by urbanization. It is a medium-sized city (approximately 100,000 residents) and has been experiencing urban sprawl into agricultural and forested areas in recent years. For this publication, we used field sampling, geostatistics (a type of statistics that uses spatial data), and Geographical Information Systems to map and provide a city-level overview of four key soil properties in Gainesville—bulk density, phosphorus, organic matter content and pH—and we explain how they vary according to land use. As part of a larger urban ecosystem study, surface soil samples were collected from random locations from five different land uses across Gainesville: commercial, forested, institutional, residential and vacant (Figures 1 and 2) and analyzed at the University of Florida's Analytical Services Laboratory (Dobbs-Brown, 2009; Escobedo *et al*. 2010; http://edis.ifas.ufl.edu/document_fr276). Note, for the purposes of this study, vacant areas were defined as abandoned sites with no existing urban infrastructure. While the properties of deeper soils are important, we chose to focus solely on the uppermost 10 centimeters of the soil profile, to minimize disturbance and damage (underground utilities, lawns, etc.) when sampling private and public property. Our sample size (n = 69) is relatively small (due to cost, time and access constraints), but this same approach has been used elsewhere (Pouyat

1. This document is FOR 275, one of a series of the School of Forest Resources and Conservation Department, Florida Cooperative Extension Service, Institute of Food and Agricultural Sciences, University of Florida. Original publication date November 2010. Visit the EDIS website at http://edis.ifas.ufl.edu.

2. Donald Hagan, PhD graduate student, School of Forest Resources and Conservation; Cynnamon Dobbs, MS graduate, School of Forest Resources and Conservation; Francisco Escobedo, assistant professor; Wayne Zipperer, research forester, USDA Forest Service; and Zoltan Szantoi, PhD graduate student, School of Forest Resources and Conservation, Institute of Food and Agricultural Sciences, University of Florida.

et al. 2007) and can provide additional information on urban soil properties reported in soil surveys for this area. This information should be of use to land-use planners, water management districts, Extension agents, and county and municipal environmental specialists in north central Florida and other medium-sized cities elsewhere.

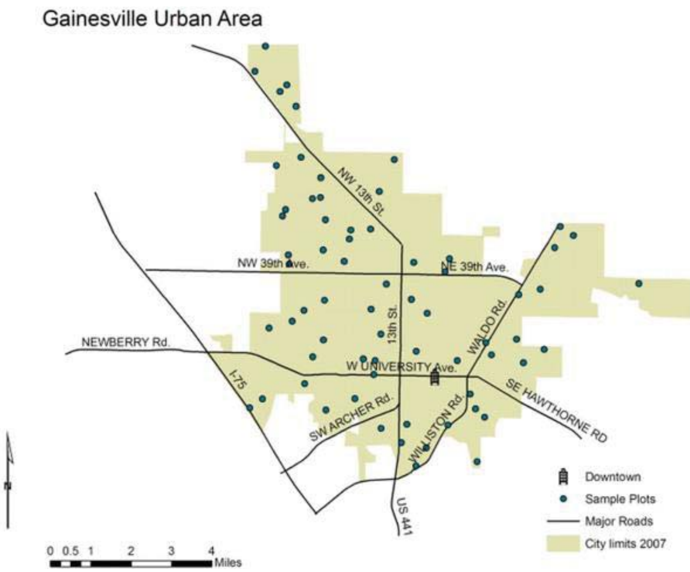

Figure 1. Map of Gainesville, Florida's city limits and sample locations.

Figure 2. Representative photo of one of five different land uses: commercial, forested, institutional, and vacant. Photos by the University of Florida and USDA Forest Service.

Bulk Density

Bulk density (mass of soil per unit volume) is a frequently used measure of soil compaction and has important implications for plant growth, water infiltration, stormwater runoff and erodibility. Generally, urban activities that disturb the soil, such as foot traffic and building and roadway construction, result in an increase in bulk density.

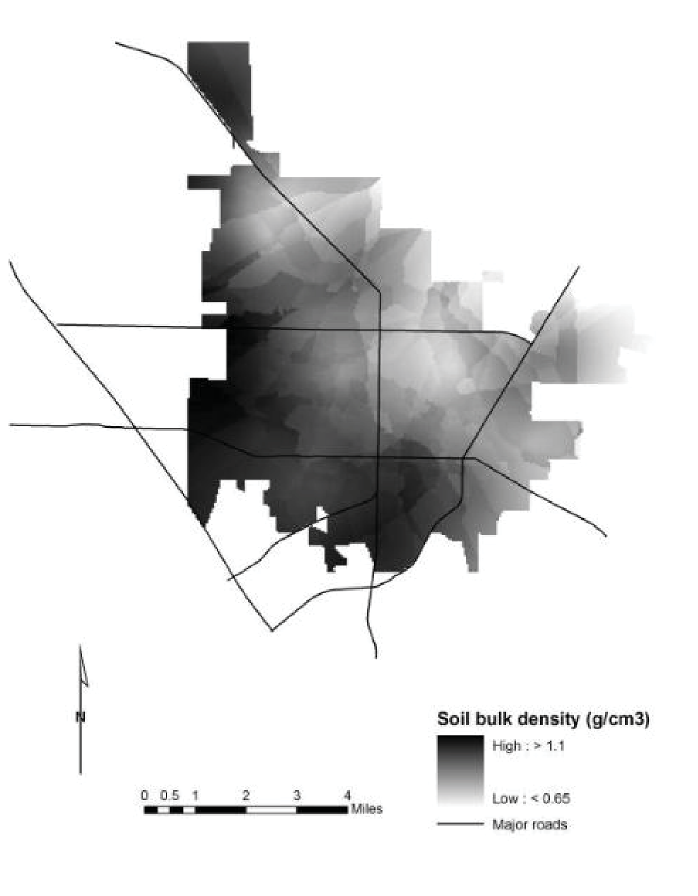

Figure 3a. Patterns of soil bulk density (g/cm^3) in Gainesville, Florida.

The presence of soil organic matter, which is often depleted in urbanized areas, can decrease bulk density. Heavily urbanized areas, therefore, typically have bulk densities that are greater than in natural areas such as forests and wetlands. Vegetation cover, however, is not necessarily a good predictor of bulk density, as urban soils covered in turf grass are among the most compacted (Dobbs-Brown, 2009).

Soil bulk density in Gainesville averaged 1.01 g/cm^3, which is considerably lower than values reported from other cities in Florida, as well as the 1.3 g/cm^3, which is considered ideal for proper plant growth and soil-water relations. A separate study of soil compaction and infiltration rates of urban construction sites in Gainesville found soil bulk densities ranging from 1.20 to 1.52 g/cm^3 (Gregory *et al*.

2006). Our measured bulk densities ranged from 0.13 g/cm^3 (very low) to 1.46 g/cm^3 (about average). In general, bulk density was highest in west Gainesville, where near-surface limestone formations are present, and in older and heavily developed commercial, industrial, residential and vacant areas in the city center (Dobbs-Brown 2009). Bulk density values commonly exceeded 1.0 g/cm^3 in both of these areas. The least compacted soils (BD ≤ 0.76 g/cm^3) were primarily in forested areas in the northern and eastern parts of the city (**Figures 3a** and **3b**).

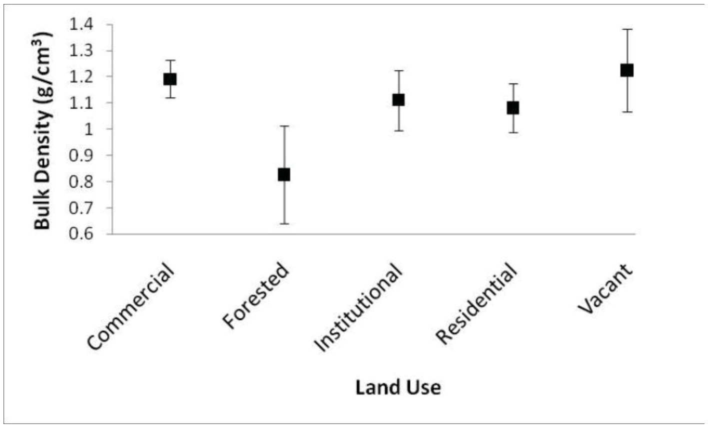

Figure 3b. Measured soil bulk density (g/cm^3) by land use in Gainesville, Florida.

Phosphorus

Phosphorus is an essential plant nutrient that is found naturally in most soils. It tends to accumulate over time, so soils affected by recent urban development—especially those consisting of sandy fill material—are often phosphorus depleted, while soils in older urbanized areas are more likely to be phosphorus enriched. This trend is especially common in urban soils that have undergone fertilization or are the recipients of phosphorus-containing wastes (e.g. septic tanks and leaks from sewer lines). From an urban soils management perspective, soil phosphorus is an important consideration, as phosphorus leached or eroded from urban soils is a primary cause of surface water and groundwater (freshwater) contamination in Florida. Since some Florida soils have a limited ability to retain phosphorus, the application of fertilizers and wastes should always be done judiciously and only after appropriate soil tests have been conducted.

Soil phosphorus content, obtained using a Mehlich-3 extractant, averaged 60.13 mg/kg, and ranged from 0.29 to 538.80 mg/kg. Phosphorus concentrations were generally highest in residential areas of southwest Gainesville and lowest in residential areas of east and northeast Gainesville and in commercial areas (Dobbs-Brown, 2009). According to the Florida Phosphorus Index, all soils in Gainesville classified by the USDA as "urban" have very high potential for phosphorus runoff, while runoff potentials for less developed areas range from low to very high. Phosphorus leaching potential ranged from very low to very high (http://edis.ifas.ufl.edu/ss319). These regional differences in runoff and leaching potential are largely due to the presence or absence of impervious surfaces and near-surface impermeable geologic formations, which inhibit infiltration, and loamy or clayey layers, which bind phosphorus and inhibit leaching. Leaching potentials are the highest in west

Figure 4a. Patterns of soil phosphorus content (mg/kg) in Gainesville, Florida.

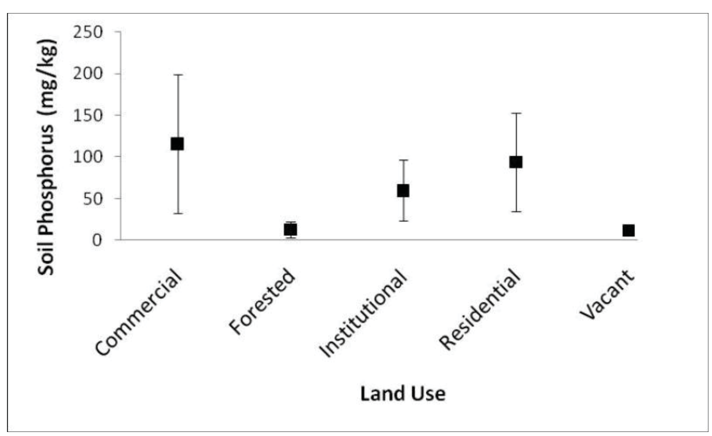

Figure 4b. Measured soil phosphorus (mg/kg) in Gainesville, Florida.

Gainesville, where much of the urban area is underlain by highly permeable limestone. Elevated phosphorus in some areas could be either geological or anthropogenic in nature, or a combination of both. Urban soils in these areas likely have a greater ability to retain applied phosphorus, but the predominance of impervious surfaces creates a high risk of loss via surface runoff and erosion (**Figure 4a** and **4b**).

Organic Matter

Soil organic matter is the term used for decomposed and/or partially decomposed remnants of living organisms (primarily plants) found in soils. A storehouse for plant nutrients like nitrogen, organic matter has important implications for a soil's ability to support plant growth. Its light, porous nature helps increase soil water retention capacity, enhance soil structure and decrease bulk density. Soil organic matter also increases a soil's ability to retain contaminants, which decreases the likelihood of offsite movement. The accumulation of soil organic matter, which is approximately 50% carbon, is a process that stores atmospheric CO_2, thereby helping to mitigate climate change (Escobedo *et al*. 2010). Since it is primarily of plant origin, it tends to accumulate in urban areas with tree or grass cover, or poorly drained areas like wetlands where decomposition is inhibited (http://edis.ifas.ufl.edu/fr276).

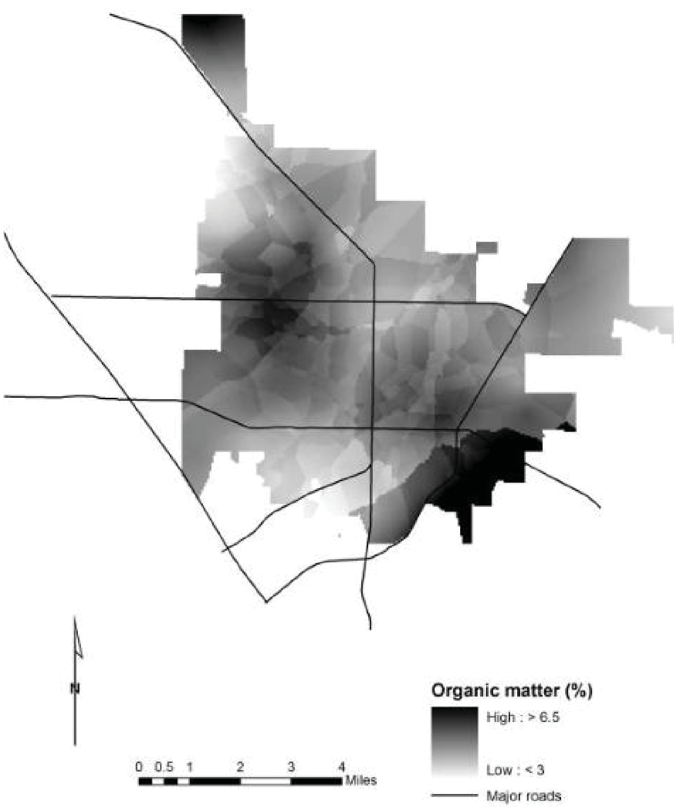

Figure 5a. Patterns of soil organic matter content (%) in Gainesville, Florida.

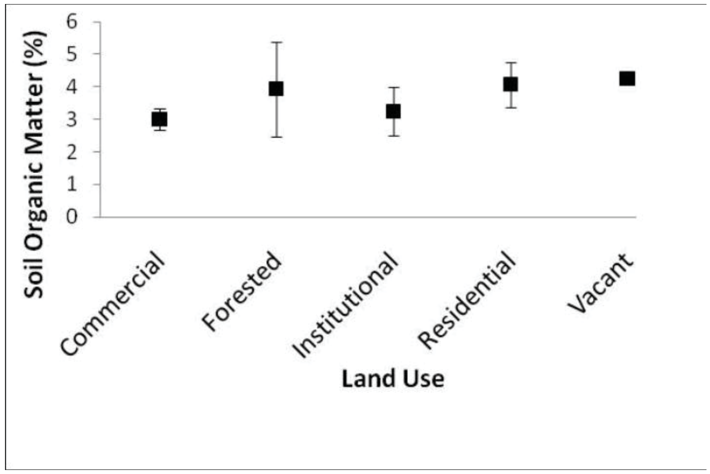

Figure 5b. Measured soil organic matter content (%) in Gainesville, Florida.

Soil organic matter content measured by loss on ignition in Gainesville averaged 3.8% of total soil weight. Like other soil properties, however, it was variable, with a range of 0.9% to 14.5%. Most of the city's soils had organic matter contents between 3 and 4%, with higher values found in forested and residential areas both in extreme southeast Gainesville (near Payne's Prairie) and in parts of west Gainesville. Small pockets of lower than average organic matter content (< 3%) were scattered throughout the city (**Figure 5a** and **5b**).

pH

Soil pH is an index of soil acidity or alkalinity. It is measured on a log-based scale of 0–14, with values below 7 being acidic and values greater than 7 being considered alkaline. It is an important consideration in urban areas because it can be used as an indicator of many soil chemical properties. Soil pH, for example, largely determines the chemical form of many soil minerals and nutrients, which in turn has implications for their toxicity, mobility and/or plant availability. Soil phosphorus is most mobile at or around pH 6, as it tends to bind with metal oxides under more acid conditions and with calcium under more alkaline conditions. Under highly acidic conditions, heavy metals can be released from the soil, often to the detriment of plants and other organisms. The decomposition of organic matter and the availability of nitrogen are also highly pH dependent.

Soil pH measured using a 1:2 soil water ratio in Gainesville averaged 5.7 (mildly acidic) and ranged from 3.6 (highly acidic) to 7.8 (mildly alkaline). In general, pH values were lowest in the forested and residential areas in the northern and eastern parts of the city and progressively increase to the south and west. This trend is probably due to the effects of soil parent material, as alkaline limestone materials are closer to the surface in western and southern Gainesville, while sandy acidic materials predominate elsewhere (Dobbs-Brown 2009). High pH values in vacant areas and in heavily developed industrial parts of the city could be caused by the prevalence of concrete, which tends to raise soil pH much in the same way as limestone (**Figure 6a** and **6b**).

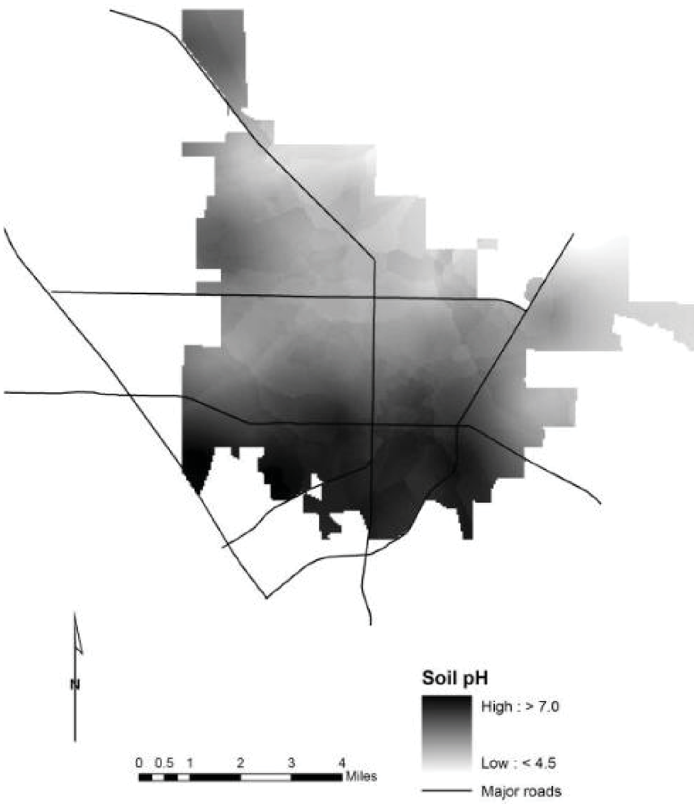

Figure 6a. Patterns of soil pH in Gainesville, Florida.

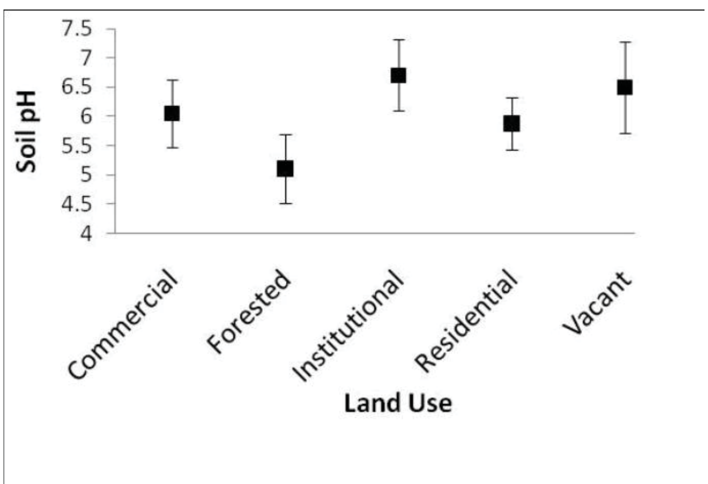

Figure 6b. Measured soil pH in Gainesville, Florida.

Conclusions

Urban soils, as indicated by bulk density, phosphorus, organic matter and pH were highly variable across Gainesville. This suggests that Gainesville's urban soils are diverse, complex and affected by numerous human and environmental factors (http://edis.ifas.ufl.edu/fr276). Improving our understanding of these factors is an essential first step in understanding urban ecosystem services, interpreting soil surveys, urban land use planning, predicting the effects of climate change, and the sustainable management of the urban soil resource.

We recommend several management practices for maintaining and enhancing urban soil quality in Gainesville and other medium-sized cities in north central Florida:

- Recognize the importance of soil physical and chemical properties (e.g. sandy texture, bulk density, phosphorus, organic matter and pH) of urban soils. Table 1 in Hagan *et al.* (2010) provides detailed information on soil properties that can be affected by urban development and geology and how they can influence your management objectives.
- Avoid or minimize management practices that disturb soil structure, cause compaction, reduce or remove organic matter and decrease water infiltration, particularly in sandy soils.
- Conduct analyses to evaluate soil contamination levels and determine the optimum retention (holding) capacity of soils that are polluted, or could become polluted with metals or organic or chemical wastes.
- Avoid excess irrigation and conduct soil tests before adding fertilizers and soil amendments.
- Preserve urban forests and maintain pervious surfaces such as natural and vegetated areas, particularly near waterways.

References

Dobbs-Brown, C. 2009. An index of Gainesville's urban forest ecosystem services and goods. Master's Thesis, University of Florida.

Escobedo, F., S. Varela, M. Zhao, J. E. Wagner, and W. Zipperer. 2010. Analyzing the efficacy of subtropical urban forests in offsetting carbon emissions from cities. Environmental Science and Policy, 13:362–372

Escobedo, F., J. Seitz, and W. Zipperer. 2009. Gainesville's urban forest structure and composition. University of Florida- IFAS, EDIS FOR 214. http://edis.ifas.ufl.edu/fr276

Gregory, J.H., M. D. Dukes, P. H. Jones, and G. L. Miller. 2006. Effect of urban soil compaction on infiltration rate. Journal of Soil and Water Conservation, 61(3) 117–124.

Hagan, D., C. Dobbs, and F. Escobedo. 2010. Florida's urban soils: underfoot yet overlooked. University of Florida-IFAS, EDIS FOR 271.

Hurt, G.W., R. S. Mylavarapu, and S. P. Boetger. 2006. UF/IFAS Nutrient Management Series: Computational Tools for Field Implementation of the Florida Phosphorus Index – Alachua County Florida. Circular 1263. Florida Cooperative Extension Service, University of Florida, Gainesville, FL.

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