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Positive effects of afforestation efforts on the health of urban soils

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ABSTRACT

Large-scale tree planting projects in cities are increasingly implemented as a strategy to improve the urban environment. Trees provide multiple benefits in cities, including reduction of urban temperatures, improved air quality, mitigation of storm-water run-off, and provision of wildlife habitat. How urban afforestation affects the properties and functions of urban soils, however, is largely unknown. As healthy soils are critical for vigorous tree growth, our study explores the impact of soil restoration as part of a large-scale urban afforestation project. We collected data on multiple soil variables over the first three years of the New York City Afforestation Project (NY-CAP). The study consists of 56 plots of 225 m^2 arrayed across an urban parkland in Queens, NYC. Each plot contains 56 trees made up of two (low richness) versus six (high richness) native species. The richness treatment was crossed with stand complexity (with shrubs and herbs versus without), and soil amendment (with compost versus without). We sampled soils in 2009 prior to project establishment, in 2010 following site preparation but just prior to planting, and again in 2011 one year after the 3–5 year old saplings were planted and plot treatments were put in place. We present results for the effects of site preparation on soil properties over time from baseline conditions in 2009 through the first year of afforestation in 2011. We also explore the impact of plot treatments (listed above and implemented right after our 2010 soil sampling) on soil parameters in 2011. Overall, site preparation improves soil conditions for the native tree saplings across time, with reductions in bulk density from $\sim$1.4 to 0.72 g cm^{-3}, acidification of the soil from pH 7.36 to 7.03, a 4-fold increase in microbially-available carbon and a 1.3-times increase in microbial biomass. Furthermore, soil carbon concentrations increased by 1.33-times between 2009 and 2011. Exploring plot treatments in 2011, compost had the largest effect, with 1.23-times more microbial biomass in composted plots, more acidic pH values (6.66 versus 7.37 in non-composted plots) and increased water holding capacity (35% versus 31% in non-composted plots). The observed changes in soil physical, chemical and biological properties suggest that site preparation and management improves traits of urban soils that are critical for infiltration, decomposition, mineralization and nutrient retention. The initial trajectories of change in these soil properties provide support for the expectation that urban afforestation – and specifically the preparation of urban soils for tree planting – will improve the health of urban soils and consequently the urban environment.

1. Introduction

Afforestation has increased in pace and extent in recent years, as policies for greenhouse gas mitigation drive the conversion of other land uses into forests (Berthrong et al., 2009). Studies on the impacts of afforestation have focused primarily on the ability of newly created forests to sequester carbon in tree biomass and soils (Guo and Gifford, 2002; Vesterdal et al., 2002; Berthrong et al., 2012). Though much of this work has focused on the establishment of plantation forests in natural areas, afforestation projects are also increasingly common in cities. There, as in natural lands, projects are intended to capture carbon as well as improve air quality, lower air temperatures, increase storm-water infiltration and create wildlife habitat (Oldfield et al., 2013). These benefits rely on healthy urban soils to facilitate vigorous tree growth and to improve the environment for soil microbes whose activities cycle nutrients through decomposition and store carbon through

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the production and aggregation of microbial-derived compounds, the primary constituents of stabilized soil organic matter (Schmidt et al., 2011). Urban afforestation efforts have traditionally relied on street-tree plantings, but more recently cities such as Auckland, London, Los Angeles and New York have implemented large-scale, tree-planting campaigns to establish contiguous stands of urban forest composed predominantly of native species (Oldfield et al., 2013).

Assessments of how urban forests benefit people living in cities unanimously conclude that tree cover improves the urban environment (Brack, 2002; Nowak et al., 2002; Davies et al., 2011). These assessments, however, are based on established mature trees primarily planted along streets. Assessments of how urban forest stands affect ecosystem properties related to the health of the environment have instead been made across urban-to-rural gradients. Gradient studies have focused primarily on remnant forest patches that compare in age and composition to rural forests (Pouyat et al., 2002; Golubiewski, 2006; Pouyat et al., 2009). Largely unanswered is what happens to the properties of urban soils as they undergo afforestation. Data assessing the efficacy of urban afforestation projects at improving soil health are, as for urban afforestation effects on ecosystem properties and processes in general, necessary but lacking (Pataki et al., 2011). Cities are then investing in urban afforestation projects without knowing whether these new forests will provide the expected benefits to the urban environment.

Of critical concern to urban afforestation is whether or not urban soils can effectively support forest vegetation. To support a growing forest, soils need to provide physical, chemical and biological conditions that provide adequate physical support, oxygen concentrations, and nutrient and water availability. To this end, many urban soils require remediation and/or improvement as urban afforestation projects are often implemented on filled wetlands or land converted from urban or industrial land uses. Urban soils are typically anthropogenically altered or created, and commonly are compacted with high percentages of human-made artifacts (>10%), including concrete, asphalt, brick and coal slag (NRCS, 2010). It is then an open question as to whether such soils can be remediated sufficiently to facilitate the establishment and growth of stands of healthy trees.

Given that successful forest growth relies on creating healthy soils, soil ecological knowledge can increase our understanding of how ecosystems respond to restoration (Ruiz-Jaen and Aide, 2005; Heneghan et al., 2008; Pavao-Zuckerman, 2008). Yet soils receive little attention in restoration projects compared to vegetation performance metrics such as growth, survival and diversity (Callaham et al., 2008; Heneghan et al., 2008). Our project helps redress this imbalance by assessing the effects of site preparation and different land managements (e.g., compost amendment and tree species diversity) on soil health at an afforestation site located in New York City (Fig. 1). Our project is a research component of the City's MillionTreesNYC Initiative. We assess how soil restoration and site managements affect key physical (e.g., bulk density), chemical (e.g., carbon concentrations) and biological (e.g., microbial biomass) properties of soils necessary for vigorous tree performance because of their influence on soil nutrient supply, aeration, moisture retention and hence root growth.

2. Methods

2.1. Site description and experimental design

Our experiment is dubbed the New York City Afforestation Project (NY-CAP). It is situated in Kissena Corridor Park (40°44′N, 73°49′W; 114 cm MAP, 13 °C MAT), a 40-ha urban park in eastern Queens, New York that includes recreational fields and facilities, a community garden and parkland. Situated in the interior of the park are 56 afforestation research plots (Fig. 1). Urban afforestation at our site, as in much of the MillionTreesNYC Initiative, focuses on restoring public parkland and so our plots were located in areas densely overgrown with and dominated by a small number of largely invasive, herbaceous species, such as mugwort (*Artemesia vulgaris*) and phragmites (*Phragmites australis*) as well as native weedy species like goldenrod (*Solidago canadensis*). The Natural Resources Conservation Service (NRCS) classified soils across Kissena as Laguardia-Ebbets complex, meaning the soils are well drained, loamy-skeletal to coarse-loamy fill soils with more than 10% human-derived artifacts. Our research plots fall in the Ebbets series, characterized by <35% coarse fragments (NRCS, 2009).

Research plots were separated into eight different treatments, consisting of a crossed arrangement of tree species richness (six species versus two species), stand complexity (with shrubs and herbs versus without), and soil amendment (with compost versus without). We refer to these treatments as diversity, shrub and compost. Replication is uneven and is organized as follows: high diversity/shrubs/compost, $n = 9$; high diversity/no shrubs/compost, $n = 9$; high diversity/shrubs/no compost, $n = 5$; high diversity/no shrubs/no compost, $n = 5$; low diversity/shrubs/compost, $n = 5$; low diversity/no shrubs/compost, $n = 5$; low diversity/shrubs/no compost, $n = 9$; low diversity/no shrubs/no compost, $n = 9$. Each plot is 15×15 m (225 m^2) and includes 56 trees planted 2.1 m from the center of each other's trunks. The tree species in low diversity plots are 28 *Tilia americana* and 28 *Quercus rubra*. The high diversity plots comprise eight individuals of *T. americana* and *Q. rubra*, plus 10 individuals of *Quercus alba*, *Celtis occidentalis*, *Carya* spp. and *Prunus serotina* (Fig. 2a and b).

Planted trees were 3–5 year old saplings measuring approximately 0.6–1.2 m in height, with root masses contained in either 1 gallon or 2 gallon ($\sim$3.79 or 7.58 L, respectively) containers. Trees were planted with a hand-held mechanized post-hole digger in holes of appropriate size to house the tree roots ($\sim$25 cm diameter and $\sim$25 cm deep). Half of the 56 plots received compost (see details below), and half were planted with shrubs (5 species, 41 plants per plot) and herbaceous plantings (7 species, 672 plants per plot), in a crossed design with the compost amendments (see paragraph above). The most represented shrub species include *Sambucus canadensis*, *Hamamelis virginiana*, and *Viburnum dentatum*; herbaceous species include *Apocynum cannabinum*, *Asclepias syriaca*, and *Panicum virgatum*. A full species list is included in Felson et al. (2013).

2.2. Site preparation

The areas for afforestation received extensive site preparation in advance of the tree, shrub and herbaceous plantings. Site preparation was performed by landscape contractors according to specifications outlined by the New York City Department of Parks & Recreation through a contractual agreement. The site preparation details outlined below were obtained from this contract.

Soils were weeded and rototilled to de-compact soil and loosen large debris to a depth of $\sim$15 cm. Debris included "objectionable material" such as trees up to 15 cm diameter, shrubby growth, brush, vines, ground covers, stumps of all sizes, roots, weeds, stones, wood, and human-derived debris (e.g., blocks of concrete and scrap metal). The compost treatment plots were then amended with compost at a rate of 2.5 m^3 per 100 m^2, incorporated to 15 cm depth. The commercial compost consisted of a blend of nutrient rich bio-solids and clean, ground wood. The compost was analyzed prior to addition and had a pH of 6.3, a bulk density of 457 kg m^{-3}, 60% C, 3.2% N, 3.7% P and 0.44% K (dry weight basis). In the following year (2010), all research plots received a surficial layer