Urban Forestry & Urban Greening 15 (2016) 149–154

Contents lists available at ScienceDirect

Urban Forestry & Urban Greening

journal homepage: www.elsevier.com/locate/ufug

Soil microbial nitrogen cycling and nitrous oxide emissions from urban afforestation in the New York City Afforestation Project

Suzanne Pierre[a,*], Peter M. Groffman[b], Mary E. Killilea[a], Emily E. Oldfield[c]

[a] Department of Environmental Studies, New York University, New York, NY, USA
[b] Cary Institute of Ecosystem Studies, Millbrook, NY, USA
[c] School of Forestry and Environmental Studies, Yale University, New Haven, CT, USA

ARTICLE INFO

Article history:
Received 11 November 2014
Received in revised form
14 September 2015
Accepted 18 November 2015
Available online 21 November 2015

Keywords:
Greenhouse gas
Urban soils
Urban forest
Parks
Compost amendment
Carbon cycling

ABSTRACT

The establishment of stands of trees in previously unforested areas (afforestation) is active in cities around the world. Given the complex and often degraded state of urban soils, there is great interest in soil biological processes that support plant growth but may also produce greenhouse gases in these new forests. We measured soil to atmosphere fluxes of nitrous oxide (N_2O) in order to determine how the presence/absence of shrubs and compost in urban afforestation site preparation affects the emission of this potent greenhouse gas. To complement the measurement of N_2O flux, microbial biomass carbon (C) and nitrogen (N), potential net N mineralization and nitrification, microbial respiration, and soil inorganic N were measured in experimentally afforested plots in New York City, USA. Results suggest that afforestation with shrubs and trees stimulates smaller fluxes of N_2O from soils than afforestation without shrubs and trees. The range of N_2O flux observed from recently afforested plots was −0.031–0.641 ng N cm^{-2} h^{-1}. There were no significant differences in N_2O fluxes and microbial biomass C between sites with shrubs and/or one–time application of compost. The results suggest that afforestation efforts to create natural vegetation structure (i.e. canopy trees with understory plants) and foster a functional microbial community through additions of organic matter may not increase emissions of N_2O to the atmosphere. Rather, this method of afforestation site preparation may tighten C and N cycles and leave N_2O emissions in these urban ecosystems unchanged.

1. Introduction

Afforestation, the establishment of stands of trees in previously unforested areas, is active in cities around the world with intentions of reducing storm water runoff, sequestering atmospheric carbon dioxide (CO_2), reducing urban ambient temperatures and providing green spaces to improve local quality of life (Kitha and Lyth, 2011; Pataki et al., 2011; Jansson, 2013; Schäffler and Swilling, 2013). As city governments seek to increase "green infrastructure" to attain observed environmental and health benefits for city residents, there is a need to evaluate the effects of creating urban green spaces on ecosystem processes (Guo and Gifford, 2002; Churkina, 2008; Jansson, 2013; Oldfield et al., 2014). Soil processes involved in carbon (C) and nitrogen (N) cycling are critical for tree establishment and growth and influence the impact of the urban forest ecosystem on the atmosphere and hydrology (Cogliastro et al., 2003; Pouyat et al., 2006; Nowak et al., 2013; Oldfield et al., 2014). Understanding the interactions among soil biogeochemical cycles and afforestation processes is critical to meeting the diverse goals of urban afforestation policies.

The natural N cycle is greatly altered by direct anthropogenic inputs of reactive N from the combustion of fossil fuels, application of agricultural fertilizers, and conversion of landscapes from natural to human-dominated spaces (Neff and Hooper, 2002; Galloway et al., 2003; Howarth, 2004; Filoso et al., 2006) and these changes may create positive feedbacks to climate change (Hungate et al., 2003; Zaehle et al., 2010). Nitrogen is made bioavailabile in soils through the microbial processes of mineralization and nitrification through which organic N is converted to ammonium (NH_4^+) and then to nitrate (NO_3^-) (Crawford and Glass, 1998) with the greenhouse gas (GHG) nitrous oxide (N_2O) emitted as a by-product. This process is linked to the removal of N from the soil system by the microbial process of denitrification through which NO_3^- is reduced to N_2O (with some release to the environment) and finally to chemically inert dinitrogen (N_2) gas.

* Corresponding author. Tel.: +1 9082856618.
E-mail addresses: sp969@cornell.edu (S. Pierre), groffmanp@caryinstitute.org (P.M. Groffman), mek5@nyu.edu (M.E. Killilea), emily.oldfield@yale.edu (E.E. Oldfield).

http://dx.doi.org/10.1016/j.ufug.2015.11.006
1618-8667/

Spatial and temporal variability in the production of N_2O from soils creates great uncertainty in estimating fluxes from natural and anthropogenic ecosystems (Groffman and Tiedje, 1989; Groffman et al., 2009). The environmental characteristics known to drive N_2O production include soil moisture, the presence of oxygen, availability of C substrates and temperature, though the interactions of these and other factors is a topic of current investigation (Morse et al., 2015; Powell et al., 2015). Relevant environmental parameters are often difficult to characterize in human-dominated systems where conditions can be altered in unknown ways (Kaye et al., 2006; Pickett and Cadenasso, 2008; Raciti et al., 2011; Pickett et al., 2013). In suburban and urban landscapes, changes to soil structure, nutrient inputs, species composition, irrigation and impervious surfaces have been shown to alter N cycling rates and N_2O fluxes to the atmosphere (Zhu et al., 2004; Kaye et al., 2006; O'Driscoll et al., 2010; Groffman et al., 2014). As research increasingly shows that human decisions in urban and exurban planning can have net negative impacts on the environment, managers and planners have sought to design more ecologically sustainable spaces (Seyfang and Smith, 2007; Kitha and Lyth, 2011; Felson et al., 2013; Baró et al., 2014). There is a strong need to determine whether efforts to mitigate climate change through improved design of urban greenspaces have positive or negative effects on N_2O emissions from urban soils.

Studies which have tested the effects of afforestation of soils with different land use histories on rates of net N mineralization and nitrification and soil inorganic N content generally suggest that afforestation decreases these variables, likely due to a changing relationship between soil organic C and N over time since afforestation (Templer et al., 2005; Luo et al., 2006; Gelfand et al., 2012; Deng et al., 2014). Singh et al. (2011) provide evidence that shifts in microbial community structure alter soil N cycling and decrease N_2O fluxes as a result of afforestation. There is a body of evidence which suggests that organic C and N inputs to soil from afforestation as well as the microbial community response to afforestation may drive changes in N cycling and alter the production of N_2O.

In the US, the The MillionTreesNYC (MTNYC) initiative is a large-scale effort to establish one million new trees, and "healthy, multi-story forests with native trees, shrubs and herbaceous layer" in particular, in New York City (Lu et al., 2014). The MTNYC initiative is a component of New York City's PlaNYC2030 sustainability agenda (www.milliontreesnyc.org). Because of the scale of its planting goals, the initiative is among the most ambitious municipal efforts to increase urban canopy and green space. The New York City Afforestation Project (NY-CAP) is a component of the MTNYC initiative developed as a designed-experiment approach to address the effects of urban environmental stressors and management on the physical attributes of soils and tree performance in urban sites (Felson et al., 2013). The NY-CAP plots were varied in shrub presence/absence, tree species richness and soil amendment with compost. To determine the importance of stand structure and initial inputs of organic matter to N_2O emissions from urban afforestation sites, we evaluated the effects of presence/absence of a shrub and herbaceous understory species and compost addition on N_2O flux in the NY-CAP. We hypothesized that shrub planting and compost application would lead to greater availability of C, higher microbial biomass and higher rates of microbial respiration that would increase rates of N uptake by microbes (immobilization) and lower rates of N transformations (nitrification and denitrification), thus decreasing N_2O emissions.

2. Methods

This research was conducted in Kissena Corridor Park (KCP) (40.749824°N, −73.823136°W) in the Flushing neighborhood of Queens County, New York, USA. Queens, NY experiences a temperate humid climate and receives an average annual rainfall of 113 cm (NOAA, 2012). The area of the study site is approximately 6.6 ha, and land use in the surrounding area is a mixture of high-density residential and commercial buildings. Soils in Kissena Corridor Park are classified as Inwood–Laguardia–Ebbets complex (Typic udorthents), well-drained loamy-skeletal to coarse-loamy fill, with ∼35% coarse fragments (NRCS, 2009).

Table 1
Treatment description, and number of plots sampled for N_2O flux per month and ambient temperature at time of sampling in December 2012 and March and November 2013.

Treatment	November (10.0 °C)	December (2.8 °C)	March (4.4 °C)
Shrubs/Herbs + Compost	$n=4$	$n=0$	$n=1$
Shrubs/Herbs only	$n=4$	$n=4$	$n=4$
Compost only	$n=4$	$n=2$	$n=0$
No additions	$n=6$	$n=4$	$n=4$

The NY-CAP research sites employed a factorial design to vary three factors in afforestation site preparation: presence/absence of shrubs and herbaceous plants, presence/absence of soil amendment with compost, and high/low tree species richness (Felson et al., 2013). This study used a subset of experimental plots ($n=12$) within KCP to make a factorial comparison of presence/absence of shrubs and herbs and presence/absence of compost. The subset of plots in this study represented the high species richness treatment group of the NY-CAP, thus tree species richness was consistent throughout the 12 plots sampled. All plots included in this study were embedded within parklands that prior to experimental preparation were overgrown with and dominated by a small number of mostly invasive, herbaceous species such as mugwort (*Artemesia vulgaris*) and phragmites (*Phragmites australis*) as well as goldenrod (*Solidago canadensis*) and other native weeds (Oldfield et al., 2014).

In 2009, the plots were weeded and rototilled, and compost treatment plots had compost applied at a rate of 2.5 cm^3 per 100 cm^3 of soil to 15 cm depth by a landscaping company contracted by the New York City Department of Parks and Recreation. The compost had a pH of 6.3, a bulk density of 457 kg m^3, and nutrient composition was 60% C, 3.2% N, 3.7% P and 0.44% K (dry weight basis) (Oldfield et al., 2014). In 2010, each experimental plot was planted with 56 individual trees (3–5 year old saplings, 0.6–1.2 m in height), 41 individual shrubs and 672 individual herbaceous seedlings (Oldfield et al., 2014). The tree species planted in these plots were *Tilia americana*, *Quercus rubra*, *Carya* sp., *Prunus serontina*, *Quercus alba*, and *Celtis occidentalis*. Shrub species included were *Cornus racemosa*, *Hamamelis virginiana*, *Lindera benzoin*, *Sambucus canadensis*, and *Viburnum dentatum* (see Felson et al., 2013 for more planting details). Herbaceous species included were *Apocynum cannabinum, Asclepias syriaca, Elymus canadensis, Euthamia graminifolia, Eupatorum purppurium, Panicum virgatum, and S. canadensis.* The experimental plots were surrounded by playing fields, foot paths, roads and high-rise buildings and were accessed by park patrons. Some of the 12 treatment plots were lost due to vandalism and storm damage, thus treatment replicates were uneven (see Table 1).

Soil cores (2–5 per plot; 15 cm length and 5 cm diameter) were taken with beveled-edge PVC corer in December 2012 from each experimental plot and composited. Soil samples were homogenized by hand to remove large and fine roots, rocks and woody organic debris. Microbial biomass C and N and were measured using the chloroform fumigation incubation method (Gundersen et al., 2012; Jenkinson et al., 2004). Test samples of 7.5 (±0.05) g were fumigated with chloroform ($CHCl_3$) for ∼12 h, reinoculated with 0.20 (±0.05) g of unfumigated fresh soil and incubated for 10 days