Science of the Total Environment 473–474 (2014) 132–138

Contents lists available at ScienceDirect

Science of the Total Environment

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

Carbon emission and sequestration of urban turfgrass systems in Hong Kong

Ling Kong [a], Zhengjun Shi [b], L.M. Chu [a,*]

[a] School of Life Sciences, The Chinese University of Hong Kong, Shatin, N.T., Hong Kong, China
[b] Shenzhen Key Laboratory of Southern Subtropical Plant Diversity, Fairy Lake Botanical Garden, Shenzhen & Chinese Academy of Science, Shenzhen, China

HIGHLIGHTS

- Carbon storage capacity at 0.05 to 0.21 kg C m^{-2} for grasses and 1.26 to 4.89 kg C m^{-2} for soils (to 15 cm depth).
- Turf maintenance contributed to carbon emissions at 0.17 to 0.63 kg Ce (carbon equivalent) m^{-2} y^{-1}.
- Turf system respiration was negatively correlated with soil carbon capacity but only in the wet season.
- Carbon stored in turfs could be offset by maintenance carbon emissions in 5–24 years.

ARTICLE INFO

Article history:
Received 3 September 2013
Received in revised form 1 December 2013
Accepted 4 December 2013
Available online 22 December 2013

Keywords:
Carbon balance
Soil
Turfgrass
Urban greenery
Maintenance management

ABSTRACT

Climate change is more than just a global issue. Locally released carbon dioxide may lead to a rise in global ambient temperature and influence the surrounding climate. Urban greenery may mitigate this as they can remove carbon dioxide by storing carbon in substrates and vegetation. On the other hand, urban greenery systems which are under intense management and maintenance may contribute to the emission of carbon dioxide or other greenhouse gases. The impact of urban greenery on carbon balance in major metropolitan areas thus remains controversial. We investigated the carbon footprints of urban turf operation and maintenance by conducting a research questionnaire on different Hong Kong turfs in 2012, and showed that turf maintenance contributed 0.17 to 0.63 kg Ce m^{-2} y^{-1} to carbon emissions. We also determined the carbon storage of turfs at 0.05 to 0.21 kg C m^{-2} for aboveground grass biomass and 1.26 to 4.89 kg C m^{-2} for soils (to 15 cm depth). We estimated that the carbon sink capacity of turfs could be offset by carbon emissions in 5–24 years under current management patterns, shifting from carbon sink to carbon source. Our study suggested that maintenance management played a key role in the carbon budget and footprint of urban greeneries. The environmental impact of turfgrass systems can be optimized by shifting away from empirically designed maintenance schedules towards rational ones based on carbon sink and emission principles.

1. Introduction

Climate change has become a public concern in recent years (Jo, 2002). While many factors may contribute to climate change, greenhouse gases (GHGs) including carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O) have attracted much attention. The atmospheric concentrations of these GHGs have steadily risen during the last century (Lal, 2008), among which CO_2 has been considered a major factor for global warming and climate change in the same period (Jo, 2002).

Urban areas have become primary sources of air pollutants as well as GHGs (especially CO_2) due to high population densities, industrial activities, fossil-fuel combustion and infrastructure construction (Kaye et al., 2004, 2006). Urban activities release substantial quantity of carbon to the atmosphere, which amounts to as much as 80% of total CO_2 emissions (Awal et al., 2010; Churkina, 2008), and leads to increases in urban temperature as manifested in the phenomenal urban heat island (UHI) effect (Awal et al., 2010).

For esthetic and environmental reasons, urban areas, on the other hand, often contain greenery vegetation that can store carbon at different capacities (Davies et al., 2011; Jo, 2002, Jo and McPherson, 1995; Nowak and Crane, 2002). Consequently, urban greenery plays a critical and important role in mitigating climate change by offsetting some of the GHG emissions and provides benefits to the urban environment (Livesley et al., 2010; Susca et al., 2011). Apart from the conventional urban greenery, such as urban forests, parks, urban lawns, roadside greenery and golf courses, new types of greenery such as green roofs and green walls have become popular in lessening the environmental problems associated with urbanization and population growth, due to the limited spaces for greenery systems in dense urban areas (Getter and Rowe, 2006; Susca et al., 2011).

* Corresponding author. Tel: +852 3943 6378; fax: +852 2603 5745.
E-mail address: leemanchu@cuhk.edu.hk (L.M. Chu).

0048-9697/$ – see front matter © 2014 Elsevier B.V. All rights reserved.
http://dx.doi.org/10.1016/j.scitotenv.2013.12.012

Urban greenery typically consists of soil and vegetation. Soil serves as the substrate to provide support and nutrients for the plants, and as a relative long-term carbon sink (Getter et al., 2009; Jo, 2002), which plays an important role in the carbon cycle (Schlesinger, 1999; Schulze and Freibauer, 2005). Soil is the largest contributor to total carbon storage in urban area (Zhao et al., 2013). It is estimated that soil organic matter (SOM) stores about four times more carbon than the atmosphere (Lehmann et al., 2008), and about 300 times more than those released by burning fossil fuels (Schulze and Freibauer, 2005). On the other hand, annual carbon emission from soil is much greater than annual anthropogenic emission. Soil respiration emits CO_2 and is a major flux in the global carbon budget (Lovelock, 2008). However, urban soils have received much less attention than agricultural and forest soils, and even less on quantifying carbon storage and emission in urban turfgrass systems (Jo and McPherson, 1995; Pouyat et al., 2002, 2006; Townsend-Small and Czimczik, 2010). Previous studies on carbon storage have focused on the differences between land types (Pouyat et al., 2007, 2009), land conversion (Jackson et al., 2002) and land history (Ren et al., 2011). There are a few studies on carbon storage in urban greenery (Davies et al., 2011; Jo and McPherson, 1995; Qian and Follett, 2002) and carbon emissions from fertilizers and irrigation in urban lawns (Livesley et al., 2010; Zirkle et al., 2011). This study investigated the carbon storage and release of urban turfgrass systems using empirical data and determined the impact of maintenance in determining an urban lawn as a carbon sink or source.

2. Materials and methods

2.1. Site description

We studied selected urban turfs in Hong Kong (22°15′44″N, 114°10′41″E) and Shenzhen (22°32′43″N, 114°04′05″E), located in the coast of southern China, which have a monsoon-influenced humid subtropical climate, i.e. wet season from April to September and dry season from October to March. We focused on data collected during the wet season from August to September 2012, and dry season in January 2013.

We collected soil samples for carbon analysis from 14 urban turfs in Hong Kong and another 14 in Shenzhen, including park lawns, campus lawns, roadside turf and athletic fields with ages ranging from 2 to 55 years. We chose five urban turfs in Hong Kong (Table 1) for our study on carbon footprint due to maintenance based on access and representation. A and E were on the university campus, while B was an athletic (cricket) field. All these three turfs were newly established in 2010. C and D were from two urban parks which opened in 1988 and 1998 respectively. *Axonopus compressus* was the dominant turfgrass species in urban parks (C and D) and lawn A on the University campus, while *Zoysia* spp. dominated in the athletic field (B) and lawn E on campus with *Cynodon dactylon* × *C. transvaalensisn* also present in the athletic field.

2.2. Survey on the carbon footprint of turf maintenance

To estimate the carbon footprints associated with turf maintenance practices in terms of fertilization, irrigation and mowing, we conducted a questionnaire survey on turf maintenance for five urban turfs in Hong Kong in 2012 (Table 2).

We calculated total carbon emissions from turf maintenances (M_C, Eqs. (1)-(5)) using similar approach by Bartlett and James (2011) with carbon equivalent emission factors (Table 3, Lal, 2004) for different sources.

$$M_C = M_f + M_e + M_i + M_c \tag{1}$$

where M_C (kg Ce y^{-1}) was the carbon equivalent emission from turf maintenances, which was the sum of the carbon emission from fuel use (M_f), electricity use (M_e), irrigation (M_i) and chemical application (M_c), Eqs.(2)–(5).

$$M_f = C_f(F_m + F_c + F_o) \tag{2}$$

where C_f was the carbon equivalent emission factor of fuel sources (kg Ce L^{-1}); F_m was the amount of fuel used in mowing (L y^{-1}); F_c was the amount of fuel on chemicals application; and F_o was other source of fuel use.

$$M_e = E_{CLP} \times C_{CLP} + E_{HEC} \times C_{HEC} \tag{3}$$

where E_{CLP} and E_{HEC} were the amount of electricity consumption (kWh y^{-1}) in studied turfs. C_{CLP} (kg Ce kWh^{-1}) was the carbon equivalent emission factor for electricity purchased from CLP Power, derived from *CLP 2012 Sustainability Report*; while C_{HEC} (kg Ce kWh^{-1}) was derived from *HEC Sustainability Report 2012*.

$$M_i = W_i \times C_w \tag{4}$$

where W_i (m^3) was the amount of freshwater used for irrigation and C_w (kg Ce m^{-3}) was the carbon equivalent emission factor for freshwater, due to the electricity used for sewage processing (0.629 kWh m^{-3}, from Water Supplies Department of Hong Kong Annual Report 2011/12).

$$M_c = Q_{H,I,F}C_{H,I,F} + Q_{N,P,K}C_{N,P,K} \tag{5}$$

where $Q_{H,I,F}$ (kg y^{-1}) were the quantities of pesticide applied, including herbicides (*H*), insecticides (*I*) and fungicides (*F*), $C_{H,I,F}$ (kg Ce kg^{-1}) were the carbon equivalent emission factors for pesticides; $Q_{N,P,K}$ (kg y^{-1}) were the quantities of fertilizer application, including nitrogenous (N) fertilizers, phosphorous (P) fertilizers and potassium (K) fertilizers. $C_{N,P,K}$ (kg Ce kg^{-1}) were the carbon equivalent emission factors for -NPK fertilizers respectively.

Table 1
Sampling sites with grass species, lawn size, establishment year, and mowing and irrigation frequency.

Sites	Turfgrass species (coverage %)	Year of establishment	Lawn size (m^2)	No. of points sampled	Mowing frequency (times y^{-1})	Irrigation frequency (times y^{-1})
A	*Axonopus compressus* (100%)	2010	1020	9	21	636
B	*Zoysia matrella* (83%) *Cynodon dactylon* × *C. transvaalensisn* (17%) *Lolium perenne*[a]	2010	9000	15	130	60
C	*Axonopus compressus* (100%)	1998	1800	9	40	104
D	*Axonopus compressus* (70%) *Zoysia japonica* (30%)	1988	2500	15	12	104
E	*Zoysia japonica* (100%)	2010	2000	9	21	636

[a] Lolium perenne was planted in the dry season from November to March.