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Full Length Article

Turfgrass Management Duration and Intensities Influence Soil Microbial Dynamics and Carbon Sequestration

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Abstract

Turfgrass systems represent one major group of intensively managed ecosystems and a potential carbon (C) sink. Turfgrass management practices critically influence C inputs to soil, soil microbial dynamics, and in turn soil C and nitrogen (N) balance. However, how management practices influence soil organic C and microbial dynamics in turfgrass systems is not well understood. We investigated the effect of management duration and intensities on soil microbial biomass, microbial activities and soil organic C contents in two golf courses dominated by Bermuda grass near Raleigh, NC, USA. In Hope Valley, two fairways were studied under the same management scheme but for a huge difference in duration (10 vs. 80 years). Whereas, in Treyburn, rough, fairway, and tee areas that were constructed in the same year but received different N and water inputs, and with different cutting frequencies were examined. Results showed conversion of a pine forest to turfgrass course reduced soil microbial biomass, microbial activities and soil organic C. Long term turfgrass planting accumulated soil organic C and N at rates of 71.9 and 10.6 g m^{-2} y^{-1} over 80 years. Moderate management intensity resulted in highest soil organic C and microbial biomass C. High N and water inputs stimulated decomposition and reduced the C accumulation in highly managed areas such as the tee area. These results suggest that management practices may critically affect organic C sequestration in turfgrass management systems. © 2014 Friends Science Publishers

Keywords: Carbon density fraction; Management duration; Management intensity; Microbial activity; Microbial carbon

Introduction

Turfgrass is widely grown for golf courses, lawns, parks, athletic field, commercial grounds, cemeteries and highway right-of-ways (Gould and Shaw, 1983). There was about 163,800 km^2 of land cultivated with turf grasses in the USA, covering 1.9% of the US land area (Milesi *et al*., 2005), or 14% of the total US cropland (Qian and Follett, 2002). Turfgrass is a major component of managed landscapes and provides many functional, recreational, commercial, and aesthetic benefits (Dougher *et al*., 2006), which include supporting biodiversity, controlling erosion, reducing dust, dissipating solar heat, providing safety for athletic and improving quality of life (Beard and Green, 1994; Bartlett and James, 2011; Tanner and Gange, 2005; Johnson *et al*., 2009).

Turfgrass with its dense shoots and well-developed root systems has the potential for C sequestration. Morgan *et al*. (2010) estimated that turfsystems across the continental United States can sequestrate 5.5×10^{12} g C each year based on lowest C sequestration rate 32 g C m^{-2} y^{-1}. In an experiment conducted in semi-arid zones in Colorado and Wyoming, Qian and Follett (2002) reported that soil organic C was sequestrated at a rate of 100 and 90 g m^{-2} y^{-1} in putting greens and fairways, respectively. Zirkle *et al*. (2011) has recently modeled that the net C sequestration rate was higher in areas with best management recommendation practices (BMPs) than in those with low management and minimal inputs. Other studies showed that storage capacity and accumulation rates of soil organic C in turfgrass varied with previous land use (Qian and Follett, 2002), soil properties (Yao and Shi, 2010), turf age (Shi *et al*., 2006a) and turfgrass management (Liu *et al*., 2011).

The frequent and intensive management disturbance such as fertilization, pesticide application, irrigation and grass-mowing in turfgrass ecosystem affects soil C dynamic. N, P, K and Si are often used to enhance grass growth characteristics and application of 2.4 g N m^{-2} wk^{-1} is best for

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rapid establishment of turfgrass (Rowland *et al*., 2010). Pesticides are propitious to turfgrass because they reduce earthworm or plant-parasitic nematode activities in the turf system (Crow *et al*., 2009; Tu *et al*., 2011). Fertilization and pesticide applications in the daily management of turfgrass industry may increase C inputs. Frequent mowing significantly can also increase C decomposition than infrequent mowing in temperate zones of America (Allaire *et al*., 2008; Slavens *et al*., 2011). How high N and water inputs affects C accumulation in highly managed areas such as tee in turf course remain unclear in southeast USA.

Soil microbes are the living part of soil organic matter, and play key roles in regulating the dynamics of soil C and other elements (Doran, 1987). Soil microbial biomass is a labile source of C and N, serving as an immediate sink of C and N (Dalal, 1998). Microbial activity greatly influences dynamics and stability of organic matter and thus C sequestration in soil (Wang *et al*., 2011). Microbial biomass and microbial activities are sensitive to land use changes and management practices (Powlson *et al*., 1987). For example, microbial biomass often declines when a grassland is converted to a forest (Dalal, 1998), whereas microbial activity generally increases after converting agricultural cropping to turfgrass (Ye *et al*., 2009). Yao *et al*. (2011) showed that lower N availability is the most important factor decreasing seasonal microbial dynamics in humid and warm region turfgrass soil.

However, it is unclear whether long-term turfgrass can increase soil C and microbial activity to a similar C level in a natural forest and if high N and water inputs stimulate decomposition and reduce the C accumulation in highly managed areas in turfgrass system. In this research, therefore, we examined soil microbial dynamics and soil C accumulation in two golf courses with one having different management history and another having different management intensity.

Materials and Methods

Experimental Details and Treatments

Two golf courses, Hope Valley Country Club (HVCC) and Treyburn Country Club (TBCC) in Durham, NC, were selected in this study. At HVCC (N 35°56′46.12″, W 78°55′57.17″), the fairway had two sections: One was at about 80 years old (Y80) planted in 1926; another was at about 10 years old (Y10) planted in 1996. Both sections were next to each other and planted Bermuda grass (*Cynodon spp.*). This fairway is slightly sloping from the north to the south. The surrounding unconverted pine forest was used as the control (CK). The soil was sandy loam (US Soil Taxonomy: White Store sandy loam, WsC). However, at TBCC (N 36°07′12.36″, W 78°51′58.89″), all areas in the course were established at the same time and planted Tifway bermudagrass (*C. dactylon x C. transvaalensis*) in a sandy loam soil (US Soil Taxonomy: WsC). We chose the rough (low management intensity — LM), fairway (moderate management intensity — MM) and tee (high management intensity — HM) for our study areas. A rough area 2 m away from the tee (low management off the tee — LMT) was also selected to examine whether high management intensity had any impacts on the rough area. It has a gradient of water and N supply and mowing frequency ranging from low management intensity to high management intensity.

Soil Sampling

Within each study area, five 12 m × 24 m sampling plots were set up except the tee area, in which only three plots were selected due to the limited size. Sampling was performed in Oct. 2007 and Apr. 2008. Ten soil cores by 10 cm depth were collected in each sampling points and five sampling point were randomly selected in each plot. The samples collected in each plot were mixed and transported to the laboratory in cooler, then passed through a 3 mm sieve and manually removed organisms and stones.

Soil Microbial Biomass C and N

The chloroform-fumigation-extraction method was used to test microbial biomass C (MBC) and microbial biomass N (MBN) (Vance *et al*., 1987; Ross, 1992). Both the non-fumigated control and fumigated (20 g dry weight equivalent each) samples were extracted by 50 mL of 0.5 moL L^{-1} K_2SO_4 after shaking for 30 min. The organic C (C_{org}) in the extracts was measured using TOC analyzer (TOC-5050A, Shimadzu Corporation, Kyoto, Japan). The MBC was calculated as follows by using 0.33 as conversion factor k_{ec} (Sparling and West, 1988):

$$MBC = (C_{org}\ in\ fumigated\ soil - C_{org}\ in\ non-fumigated\ soil) / k_{ec}$$

After digestion with alkaline persulfate oxidation (Cabrera and Beare, 1993), the N concentration in the extracts was tested by Lachat flow injection analyzer (Lachat Instruments, Milwaukee, WI, USA). The MBN was calculated using the follow equation and the conversion factor k_{en} is 0.45 (Jenkinson, 1988):

$$MBN = (total\ N\ extracted\ from\ fumigated\ soil - total\ N\ extracted\ from\ non-fumigated\ soil) / k_{en}$$

Soil Microbial Respiration

Incubation-alkaline absorption method was used to measure microbial heterotrophic respiration (Coleman *et al*., 1978). Twenty gram dry mass equivalent soil was weighed and water contents were adjusted to 60% water holding capacity (Alef, 1995), then placed in a one L Mason jar with a beaker containing 5 mL 0.5 mol L^{-1} NaOH (Forster, 1995; Hu and van Bruggen, 1997). The jars were incubated at 25ºC in the dark after sealing immediately. After 7 d incubation, beakers were replaced with one containing fresh NaOH solution and incubated for an additional 7 d. The CO_2 captured in the

NaOH was titrated with 0.1 mol L^{-1} HCl to determine the amount of CO_2 released by the soil microbes. Microbial respiration was expressed as mg CO_2 kg^{-1} soil d^{-1} by averaging the two data. Microbial metabolic quotient (*q* CO_2) was accounted by dividing respiration rates by MBC.

Total C and N in Soil

A Perkin-Elmer 2400 CHNS/O elemental analyzer (Norwalk, CT, USA) was used to determine total soil organic C (SOC) and soil organic N (SON) after sample air-drying and grinding.

Organic Carbon Fractionation and Soil Grass Derived C

A procedure modified from Baisden *et al.* (2002) was used to test soil organic carbon density fractionation. Fifty g of soil sample was first extracted with 50 mL of distilled water in a 100 mL flask. After gentle dispersal by hand, the flask was left standing overnight at 25ºC. The supernatant was then subjected to filtration through Whatman No.1 filter paper. The materials collected on the filter paper were the light OC fraction (F1, d < 1.0 g cm^{-3}). The soil left in the flask was resuspended by hand-stirring in 50 mL potassium iodide solution (d = 1.6 g cm^{-3}). The flask was then left standing at room temperature for at least 1 h. The heavy OC fraction (F2, d < 1.6 g cm^{-3}) was collected by filtration and the residue was the very heavy fraction (F3, d > 1.6 g cm^{-3}). All fractions were oven-dried at 65ºC and ground to a fine powder before C determination on the Perkin-Elmer 2400 CHNS/O elemental analyser. Determination of ^{13}C was performed on a Thermo Finnigan DELTAPlus continuous flow isotope ratio mass spectrometer (CF-IRMS, Bremen, Germany).

The golf courses were established on long term C_3 forest sites, and have been grown with C_4 bermudagrass since their establishment. Therefore, grass-derived C in the soil could be estimated. The single isotope, two source mixing model (Phillips and Gregg, 2001) was used to calculate the mean proportion (f_G) of the grass-derived C in the whole soil or soil fractions and the standard error (SE) of the f_G:

$$f_G = (\delta_T - \delta_S) \Big/ (\delta_G - \delta_S)$$

$$SE_{f_G} = \sqrt{[\sigma^2{}_{\delta_T} + f^2{}_G \sigma^2{}_{\delta_G} + (1 - f_G)^2 \sigma^2{}_{\delta_S}] \Big/ (\delta_G - \delta_S)^2}$$

δ_G represents the mean δ^{13} C value for the grass, and $\sigma^2 \delta_G$ represents the δ^{13} C variance for the grass. δ_S refers to the mean δ^{13} C value for the initial soil in the whole soil or the soil fractions, and $\sigma^2_{\delta s}$ refers to the mean δ^{13} C variance for the initial soil in the whole soil or the soil fractions. δ_T is the mean δ^{13} C value for the treated soil in the whole soil or the soil fractions, and $\sigma^2_{\delta T}$ represents the mean δ^{13} C variance for the treated soil in the whole soil or the soil fractions.

Statistical Analysis

Differences in carbon and microbial dynamics among management durations and intensities were analyzed using a paired t-test. Analyses were carried out by SAS 9.0 software (SAS Systems, Cary, NC, USA).

Results

Microbial Biomass C and Microbial Biomass N

Management duration had a great impact on MBC and MBN. In HVCC, MBC was higher in the turfgrass areas than pine forest in the fall, 2007 (Fig. 1a), with 31.6% and 21.3% greater in Y10 and Y80 turfgrass areas compared with the pine tree. However, MBC was respectively 16.3% and 6.4% lower in Y10 and Y80 than in CK in the spring, 2008 (Fig. 1a). Compared with the CK, MBN was 17% and 56% higher in Y10 and Y80 in fall 2007. In spring 2008, however, MBN was 34.9% and 10.7% lower in Y10 and Y80 than in CK (Fig. 2a).

Management intensity also influenced MBC and MBN. In TBCC plots, MBC was higher in LMT than the others in 2007 (Fig. 1b). In 2008, the highest MBC was found in MM, which was 18.3%, 4.8% and 14.7% higher than in LM, HM and LMT. Likewise, MBN had the similar trend to MBC, with the highest value found in LMT in 2007 (Fig. 2b), and in MM in 2008. No differences in MBN were observed among others.

Microbial Respiration

In HVCC plots, soil microbial respiration (SMR) was enhanced by 17~47% and -3~26% in Y80 and Y10 for both sampling dates compared with CK, respectively (Fig. 3a). Similar treads existed for soil microbial metabolic quotient (*q* CO_2). The greatest *q* CO_2 was found in Y80 for two sampling dates (Fig. 4a). In TBCC, SMR was obviously lower in MM than in others in 2007 (Fig. 3b), while was highest in MM in 2008. The *q* CO_2 was higher in LM than in MM (p = 0.0018) and HM (p = 0.0369) in 2007, but greater in LM and MM than in HM and LMT in 2008 (Fig. 4b).

Soil Total C and N

Soil total organic C and organic N were highest in Y80 in HVCC, with 26~67% and 61~74% higher than others (Fig. 5a and b). The ratio of C to N was highest in CK with 19.8, followed by Y10 (13.4) and Y80 (14.1). In TBCC, total organic C and organic N decreased in order of MM > LM > LMT > HM. The ratio of C to N ranged from 12.8 to 14.0 (Fig. 5a and b).

Soil Grass Derived C

Grass derived C accounted for 81.6%, 77.8% and 75.7% of C in light organic matter (OM) fraction, heavy OM fraction

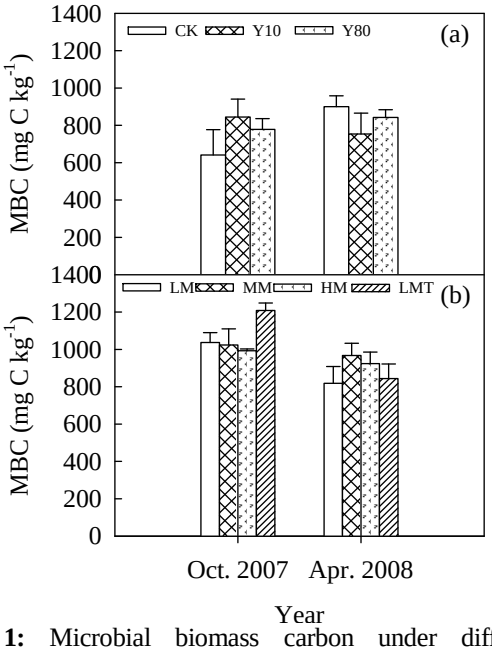

Fig. 1: Microbial biomass carbon under different management durations (a) and intensities (b). CK = pine tree. Y10 = management duration about 10 years. Y80 = management duration about 80 years. LM = low management intensity. MM = moderate management intensity. HM = high management intensity. LMT = low management off the tee. MBC = microbial biomass carbon. Vertical bars represent SEM

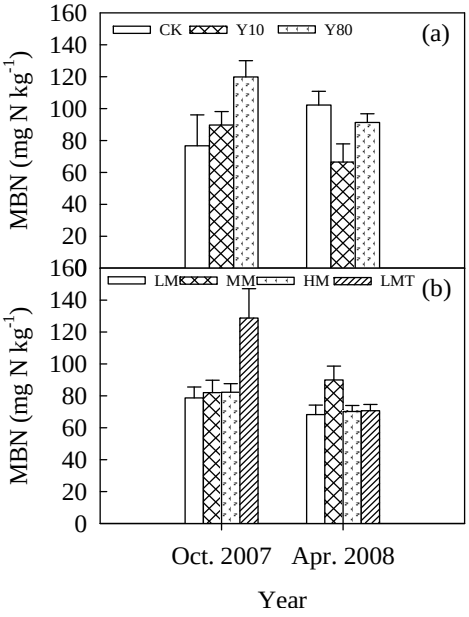

Fig. 2: Microbial biomass nitrogen under different management durations (a) and intensities (b). CK = pine tree. Y10 = management duration about 10 years. Y80 = management duration about 80 years. LM = low management intensity. MM = moderate management intensity. HM = high management intensity. LMT = low management off the tee. MBN = microbial biomass nitrogen. Vertical bars represent SEM

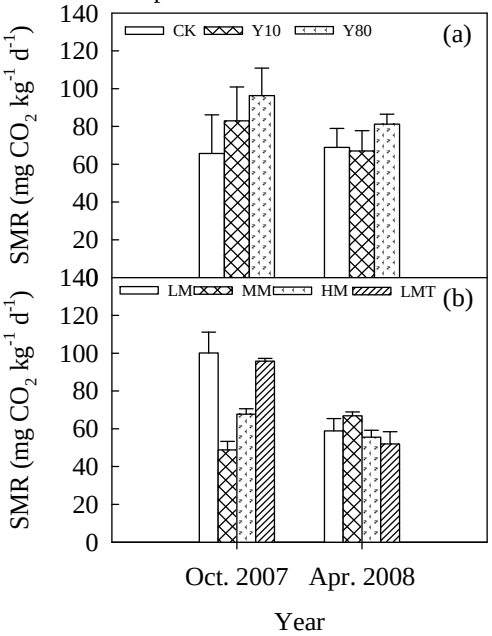

Fig. 3: Microbial respiration rate under different management durations (a) and intensities (b). CK = pine tree. Y10 = management duration about 10 years. Y80 = management duration about 80 years. LM = low management intensity. MM = moderate management intensity. HM = high management intensity. LMT = low management off the tee. SMR = soil microbial respiration. Vertical bars represent SEM

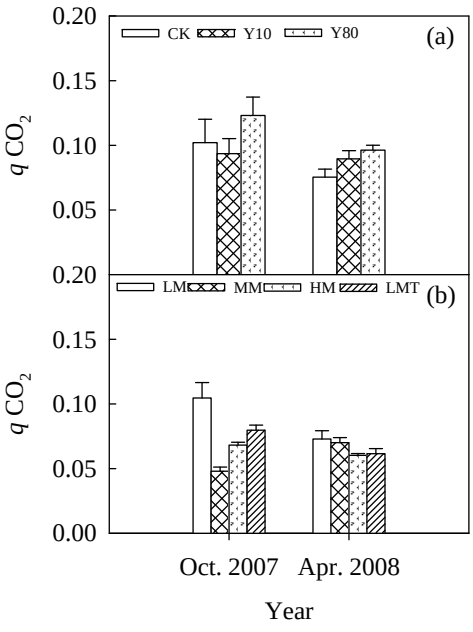

Fig. 4: Microbial metabolic quotient under different management durations (a) and intensities (b). See Fig. 1 for abbreviations. Values are means ± S.E. with the sample size n = 5 (CK, Y10, Y80, LM, MM) or n = 3 (HM, LMT)

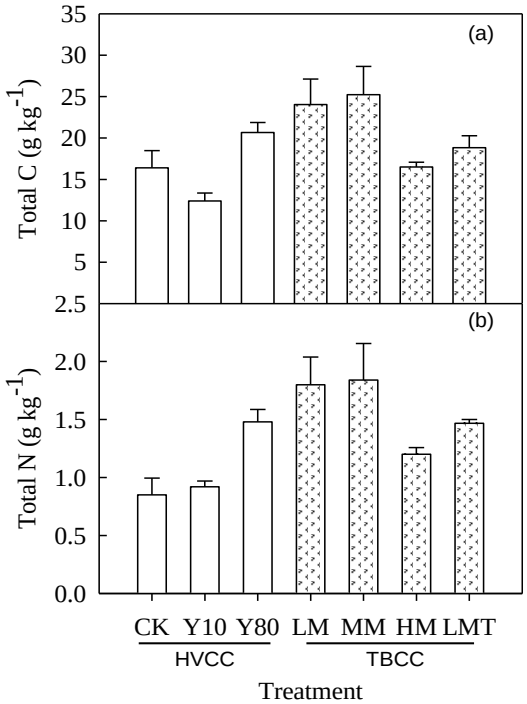

Fig. 5: Soil carbon (a) and nitrogen (b) under different management durations and intensities in April 2008. CK = pine tree. Y10 = management duration about 10 years. Y80 = management duration about 80 years. LM = low management intensity. MM = moderate management intensity. HM = high management intensity. LMT = low management off the tee. HVCC = Hope Valley Country Club. TBCC = Treyburn Country Club. Vertical bars represent SEM

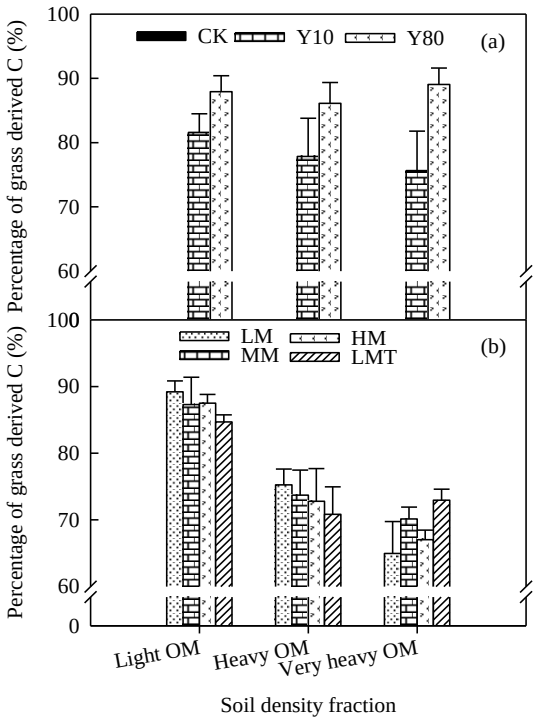

Fig. 6: Percentage of grass derived C under different management durations (a) and intensities (b) in April 2008. CK = pine tree. Y10 = management duration about 10 years. Y80 = management duration about 80 years. LM = low management intensity. MM = moderate management intensity. HM = high management intensity. LMT = low management off the tee. Light OM = light organic matter. Heavy OM = heavy organic matter. Very heavy OM = very heavy organic matter. Vertical bars represent SEM

and very heavy OM fraction, respectively, after 10-year turfgrass management. Higher percentage of carbon derived from grass was found in Y80 than in Y10 (Fig. 6a). In TBCC, grass derived C was higher in MM and LMT than in others in very heavy OM fraction (Fig. 6b).

Discussion

Results obtained in this experiment showed that long management duration and moderate management intensity of turfgrass improved soil microbial biomass and microbial activity, and soil C and N. Microbial biomass C, microbial biomass N and microbial respiration were lower in the 10-year plots than the control, but all showed improvements under the 80-year management. Soil microbial biomass and activity are usually dependent on soil organic C (Jenkinson and Ladd, 1981). Long-term steady turf managements increase organic C inputs to soil via grass clippings deposition at soil surface and root turnover in the deeper soil (Shi *et al.*, 2006b; Qian *et al.*, 2010). Generally, the C accumulation rate in managed turfgrass was higher in the first 25-year after turfgrass was established, and continued 45-year after turfgrass establishment (Qian and Follett, 2002). In our 80-year turfgrass system, average organic C and N sequestration rates were 71.9 g m^{-2} y^{-1} and 10.6 g m^{-2} y^{-1}, respectively. It has been reported that the average soil organic C sequestration rate for USA lawns is 46.0-127.1 g m^2 y^{-1} (Zirkle *et al.*, 2011), and the soil N sequestration rate is approximately 37 g m^2 y^{-1} with clippings returned and a 150 g m^2 y^{-1} N fertilization rate (Qian *et al.*, 2003).

Application of fertilizers to the turfgrass systems not only maintains turfgrass growth, but also may improve soil C and N accumulation in soil. Plant growth is usually N-limited and N application can stimulate plant growth, and thus increase C inputs to soil, facilitating C and N retention (Hu *et al.*, 1998). In the present research, organic C and N were 25% and 75% higher in the 80-year managed turfgrass soil than in undisturbed pine forest soil, respectively. It has been reported that soil N loses 75% after the land-use is changed from forest to agricultural systems, and it takes 200-year for the lost N to recover in the natural process (Knops and Tilman, 2000).

Management intensity affects microbial parameters and soil C and N accumulation through its induced changes in

resource availability. Under lower intensity management, microbes and their activities could be restricted, because of limited water and nutrients (including carbon) availability. However, although high intensity managed turfgrass systems received sufficient water and nutrients supply, frequent disturbance such as mowing and cutting suppressed microbial biomass and microbial activities because the time interval for microbial colonization was short. On the tee areas, mowing activity cuts and removes grass away in order to maintain visual performance and playing convenience, thus leading to lower C inputs to soils. Additionally, high water inputs and frequent coring also stimulated C decomposition in the high management system (Qian and Follett, 2002). Furthermore, inorganic fertilizer application could greatly decrease fungal biomass (Smith *et al.*, 2003), and fungicides also directly inhibited soil fungi. Together, it was likely that soil microbial biomass C, N and activity, and soil C accumulation were highest under the moderate management intensity.

Although the soil microbial parameters, such as microbial biomass and microbial respiration recovered after long management, compared to the undisturbed natural system, the soil microbial community composition might change. In this study, higher microbial metabolic quotient (qCO_2, the community respiration per biomass unit) in the 80-year turfgrass system implied that r-strategists microbial species became more dominant, because these species have the capacity to quickly adapt to frequently disturbed environment (Andrews and Harris, 1986). Zhang *et al.* (2005) also reported that the reducing anthropogenic management intensity may facilitate the development of microbial communities, which facilitate C retention in turfgrass soil.

It is noted that microbial parameters in different systems varied between two sampling events. Such variation might be explained by soil moisture differences. In 2007 dry year, soil moisture in CK (16.9%) were driers than in Y10 (23.6%) and Y80 (26.1%) in HVCC as the latter received regular irrigation to maintain the turfgrass. In TBCC, soil moisture in the lower management system LM (21.6%) and LMT (21.5%) were similar to that in MM (24.9%) because the former (LM and LMT) was always covered with grass like a blanket, which reduced water loss. However, the weather was normal in 2008. Soil moisture might have fewer impacts on microbial parameters than other factors.

In crux, long-term management and moderate management intensity of turf improved microbial biomass and microbial activity, and enhanced soil C and N accumulation. The average sequestration rate of carbon and nitrogen in turfgrass soil was 71.9 g m^2 y^{-1} and 10.6 g m^2 y^{-1}, respectively. Grass derived C accounted for 65.0-89.2% of soil total organic C.

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