Soil Biology & Biochemistry 43 (2011) 1536–1543

Contents lists available at ScienceDirect

Soil Biology & Biochemistry

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

Seasonal variations of soil microbial biomass and activity in warm- and cool-season turfgrass systems

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ARTICLE INFO

Article history:
Received 16 December 2010
Received in revised form
17 March 2011
Accepted 30 March 2011
Available online 15 April 2011

Keywords:
Microbial biomass
Microbial respiration
N mineralization
Soil enzyme activity
Turfgrass

ABSTRACT

Plant growth can be an important factor regulating seasonal variations of soil microbial biomass and activity. We investigated soil microbial biomass, microbial respiration, net N mineralization, and soil enzyme activity in turfgrass systems of three cool-season species (tall fescue, *Festuca arundinacea Schreb.*, Kentucky bluegrass, *Poa pratensis* L., and creeping bentgrass, *Agrostis palustris* L.) and three warm-season species (centipedegrass, *Eremochloa ophiuroides* (Munro.) Hack, zoysiagrass, *Zoysia japonica* Steud, and bermudagrass, *Cynodon dactylon* (L.) Pers.). Microbial biomass and respiration were higher in warm- than the cool-season turfgrass systems, but net N mineralization was generally lower in warm-season turfgrass systems. Soil microbial biomass C and N varied seasonally, being lower in September and higher in May and December, independent of turfgrass physiological types. Seasonal variations in microbial respiration, net N mineralization, and cellulase activity were also similar between warm- and cool-season turfgrass systems. The lower microbial biomass and activity in September were associated with lower soil available N, possibly caused by turfgrass competition for this resource. Microbial biomass and activity (i.e., microbial respiration and net N mineralization determined in a laboratory incubation experiment) increased in soil samples collected during late fall and winter when turfgrasses grew slowly and their competition for soil N was weak. These results suggest that N availability rather than climate is the primary determinant of seasonal dynamics of soil microbial biomass and activity in turfgrass systems, located in the humid and warm region.

1. Introduction

Nitrogen fertilizers are routinely applied to turfgrasses to maintain adequate growth and visual quality. Applications are timed to coincide with growth-driven N demand, namely late spring and summer for the warm-season species vs. early spring and fall for the cool-season species. Turfgrass fertility programs are structured around such applications; they rarely consider the seasonal contributions from mineralization of soil organic N.

Microbial biomass turnover is an influential soil process dictating the amount of N stored or released from the biomass and thus soil available N for plant uptake (Vitousek and Matson, 1984; Wardle, 1998). Microbial N mineralization represents another crucial soil process regulating the amount of inorganic N for plant uptake. Yet, these soil processes have not been fully understood in turfgrass systems and therefore cannot be incorporated into turfgrass fertilization programs.

Based on their tolerance to temperature extremes and photosynthetic strategy, turfgrasses are grouped into either warm-season (C_4) or cool-season (C_3) species (Beard, 1973; Turgeon, 2005). Compared to warm-season, cool-season grasses are less efficient in fixing CO_2 due to higher rates of photorespiration. Cool-season grasses are most productive with temperatures of 16–24 °C and therefore grow most rapidly in spring and then slow or even stop entirely during summer, followed by another growth flush in fall (Turgeon, 2005). By contrast, warm-season grasses grow best with temperatures of 27–35 °C in summer and are dormant or have limited growth during winter. Based on these differences in energy capture and seasonal growth patterns, warm- and cool-season grasses may differentially affect soil microorganisms, both quantitatively and temporally.

Temperature and moisture are important environmental factors influencing soil microbial growth and activity. There is an optimum level for each at which microbial growth and activity are greatest,

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0038-0717/$ – see front matter © 2011 Elsevier Ltd. All rights reserved.
doi:10.1016/j.soilbio.2011.03.031

and above or below which growth and activity decline (Paul and Clark, 1996). Seasonal variations in soil temperature and moisture directly control temporal fluctuations in soil microbial biomass and activity in some ecosystems (Vangestel et al., 1992; Corre et al., 2002; Bell et al., 2008). Additionally, the effects of temperature and moisture may be indirect, mediated by plant C supply. Lynch and Panting (1982) reported that although temperature influenced soil microbes, microbial biomass was primarily determined by the availability of substrates derived from plant roots. They found that soil microbial biomass increased as roots grew, reached a maximum around the time of maximum root production, and thereafter declined. Based on published data of seasonal variations in microbial biomass from natural and managed ecosystems, Wardle (1998) concluded that the magnitude of temporal variability, which was determined as the coefficient of variation, was related to geographic locations, soil pH, and soil C content but not to vegetation types or ecosystem management (i.e., forests, grasslands, and arable soils). However, the author found that the temporal patterns of microbial biomass were ecosystem- and/or study site-specific.

This study addressed the degree to which warm- and cool-season turfgrasses regulated soil microbial biomass and activity in the warm-humid southeastern US. We hypothesized that the magnitude of changes in microbial biomass and activity would be independent of turfgrass types, while the fluctuation patterns would be grass type-specific. Given that organic C input through grass clippings, root exudates and root biomass turnover is likely an important regulator, cool-season grasses would have lower microbial biomass and activity during the summer, whereas warm-season grasses would have lower microbial biomass during the winter. Both warm- and cool-season grasses would have higher microbial biomass and activity in late spring due to increasing temperature and active grass growth. However, if soil organic C rather than newly added organic C from turfgrasses is the major C source, then microbial biomass and activity would be mainly dependent on fluctuations of optimum temperature and moisture. Because turfgrass systems are normally irrigated, temperature regimes would determine the dynamic patterns of microbial biomass and activity. In this case, microbial biomass and activity were expected to be greater in late spring and summer, but lower in winter months.

Grasses of the same type (warm- vs. cool-season) may differ in ways that could impact soil microorganisms. For example, bermudagrass is relatively deep rooted, whereas zoysiagrass is shallow rooted; consequently, the depth profile for microbial activity might be affected. To better compare the impacts of warm- versus cool-season turfgrasses on soil microbial properties, this study was conducted on several warm- and cool-season turfgrass systems.

2. Materials and methods

2.1. Study site and soil sampling

The study was conducted at the Sandhills Research Station of North Carolina State University, NC, USA. Turfgrass plots were established in 2001 on sandy soils (sandy, siliceous, Thermic Psammentic Hapludults). We randomly chose six field plots representing three warm-season species (bermudagrass, *Cynodon dactylon* (L.) Pers.; centipedegrass, *Eremochloa ophiuroides* (Munro.) Hack; and zoysiagrass, *Zoysia japonica* Steud) and three cool-season species (creeping bentgrass, *Agrostis palustris* L.; Kentucky bluegrass, *Poa pratensis* L.; and tall fescue, *Festuca arundinacea Schreb.*) to examine the temporal changes in soil microbial properties as functions of turfgrass types.

All turfgrass plots were irrigated as needed to prevent water stress; therefore, the frequency and timing of irrigation varied with turfgrass growth stages and local weather (Fig. 1). Pesticides were used on a preventative schedule, but specific chemicals, rates, and timing differed among turfgrass species (Fig. 2). Timing and rates of fertilization also varied with turfgrass species (Fig. 2). Generally, fertilization rates were lower for warm-season than cool-season turfgrass species, averaging 200, 122, 178, 240, 284, and 280 kg N ha^{-1} yr^{-1}, 12, 6, 10, 27, 16, and 16 kg P ha^{-1} yr^{-1}, and 65, 38, 64, 167, 109, 108 kg K ha^{-1} yr^{-1} for bermudagrass, centipedegrass, zoysiagrass, creeping bentgrass, Kentucky bluegrass, and tall fescue, respectively. Grasses were mowed at heights specific for the species, ranging from ~0.4 cm for creeping bentgrass to 7 cm for tall fescue. Again, mowing frequency and timing were different among turfgrass species. Mowing could be as often as every other day during the rapid growth of grasses, but all clippings were recycled. We did not record mowing frequency and amounts of clippings recycled. Our previous measurements of C and N contents of turfgrasses including bermudagrass and tall fescue showed that C:N ratios of grass clippings were less than 20:1.

Soils were sampled from the selected field plots on September 5, 2006, December 8, 2006, February 22, 2007, and May 15, 2007. This sampling scheme represented different growth stages of turfgrasses and also reflected seasonal climate changes (Fig. 1). Nine soil cores (5 cm dia. × 7.5 cm depth) were taken randomly from each field plot, placed in ice-cold coolers, transported to the laboratory, and then mixed to form a composite soil sample. Soil was sieved (<4 mm) and most roots and grass residues were removed prior to the analysis of soil properties.

2.2. Soil physical and chemical properties

Soil water content on a weight basis and soil pH (slurry method) were measured to establish the baseline relationship between changes in soil microbial properties and changes in soil physical and chemical properties. Soil inorganic N was extracted with 1 M KCl, and the filtrate was analyzed for NH_4^+ and ($NO_3^- + NO_2^-$)–N using a Lachat flow-injection auto-analyzer (Lachat Instruments, Mequon, WI). Water-extractable soil organic C and total N were measured using a total organic carbon analyzer (TOC-VCPN, Shimadzu) using a 1:4 wt:vol distilled H_2O extraction (Haney et al., 2001). Water-extractable organic N was calculated as the difference between water-extractable-total N and -inorganic N measured

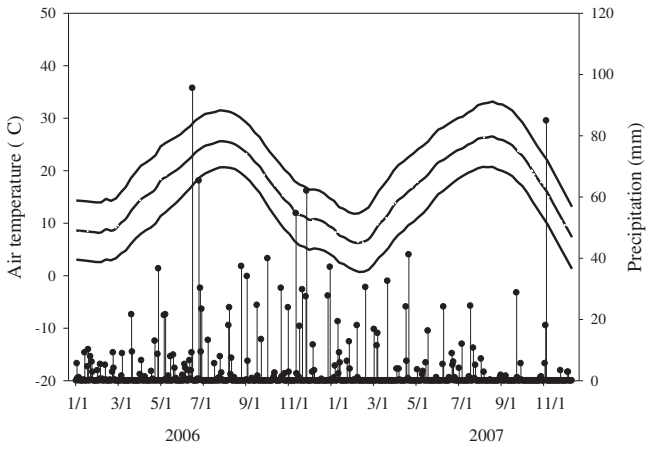

Fig. 1. Daily air temperatures and precipitations from January 2006 to December 2007 in Sandhills research station, Sandhills, North Carolina. Three solid lines represent daily maximum, average, and minimum temperatures. Drops lines represent the amount and timing of precipitation.