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# Interactions between N fertilization, grass clipping addition and pH in turf ecosystems: Implications for soil enzyme activities and organic matter decomposition

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ABSTRACT

Turf has been acknowledged as an important ecosystem with potential for soil C sequestration. As a major process dictating soil C storage, organic matter decomposition has received little attention in turf systems. Given that soil enzyme-catalyzed biochemical reactions are the rate limiting steps of organic matter decomposition, we examined the activities of oxidative and hydrolytic soil enzymes and their relations with soluble organic compounds and soil C and N mineralization in two turf chronosequences with contrasting soil pH and in response to N fertilization and grass clipping addition. In comparison with turf ecosystems under acidic soil, phenol oxidase activity was about two-fold greater in turf ecosystems under alkaline soil and positively correlated to about two-fold differences in soluble phenolics and dissolved organic C between alkaline and acidic soils. However, the activities of hydrolytic enzymes including cellulase, chitinase, and glucosidase were lower in alkaline soil. It appears that the high concentration of soluble phenolics inhibited the activities of hydrolytic enzymes that in turn limited the decomposition of dissolved organic C and resulted in its accumulation in alkaline soil. Nitrogen mineralization was comparable between alkaline and acidic soils, but $CO_2$ evolution was about two-fold greater in alkaline soil, possibly due to considerable abiotic carbonate dissolution. We observed that mineral N input at 60 mg N $kg^{-1}$ soil had very minor negative effects on the activities of both phenol oxidase and hydrolytic enzymes. Grass clipping addition did not affect the activity of phenol oxidase, but increased the activities of soil chitinase, cellulase, glucosidase, and glucosaminidase by up to 20% and also soluble phenolics in soil by about 10%. Our results suggest that soil phenol oxidase might regulate the activities of hydrolytic soil enzymes via its control on soluble phenolics and function as an ‘enzymatic latch’ to hold soil organic C in highly managed turf ecosystems. While soil pH is important to affect phenol oxidase activity and therefore decomposition, management practices, i.e., N fertilization and grass clipping addition may indirectly affect the decomposition through enhancing turfgrass productivity and thus soil C input.

## 1. Introduction

Turf has been documented as an important ecosystem of soil C sequestration (Qian and Follett, 2002; Bandaranayake et al., 2003). After turf establishment, soil C could be accumulated at ~1.0 Mg C $ha^{-1}$ $y^{-1}$ and this rate was ~3-fold greater than that in unmanaged grasslands developed from previously disturbed fields (Post and Kwon, 2000; Bandaranayake et al., 2003). Fertilization, cycling of grass clippings, and irrigation were recognized as the vital management practices for improving the ability of turf soil C sequestration (Milesi et al., 2005). Clipping returns could increase soil C sequestration by 11–59% (Qian et al., 2003). Despite the advance of knowledge made from survey and modelling, little information is available on basic principles dictating soil C sequestration in turf ecosystems. Specifically, decomposition of soil organic matter, a major process regulating soil C sequestration has received little interest. Mechanistic understanding on soil organic matter decomposition in turf ecosystems is needed because it helps to predict how climate and management practices affect soil C dynamics. Today, 20 million hectares of turfgrass in the US are widespread on lands of various acidity and alkalinity as home lawns, roadsides, parks, sport fields, commercial landscapes, and

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golf courses (Brown et al., 2005; Milesi et al., 2005). To better manage turf capacity of C storage, we need to understand soil organic matter decomposition as affected by soil pH and turf management practices.

For decades, acidic soils have been the focus to learn pH effects. Most studies corroborated that acidic pH retarded, and thus liming could enhance the decomposition of soil organic matter (Jenkinson, 1977; Amato and Ladd, 1992; Motavalli et al., 1995). Studies that examined organic matter decomposition in a broad range of soil pH seem to produce contradictory results. One study reported that organic matter decomposition was greatest at the neutral pH and reduced with increasing or decreasing pH from neutral (DeLaune et al., 1981), while another study showed that organic matter decomposition increased from slightly acidic to alkaline soil pH (Amato and Ladd, 1992). Inconsistent relationship between soil pH and soil C decomposition may possibly be due to other confounding soil factors. In some soils, for example, significant increases in soil $CO_2$ efflux likely came from abiotic dissolution of soil $CaCO_3$ (Stevenson and Verburg, 2006; Bertrand et al., 2007). Nevertheless, soil pH effects on the decomposition have been mainly attributed to pH-associated biological changes including biomass, activity, and composition of soil microbial community (DeLaune et al., 1981; Adams and Adams, 1983; Zelles et al., 1987; Shah et al., 1990; Nodar et al., 1992).

Soil pH also affects the activity of soil enzymes through its controls on microbial enzymatic production, ionization-induced conformational changes of enzymes, and/or availability of substrates and enzymatic co-factors (Tabatabai, 1994). A global-scale meta-analysis using data from 40 ecosystems has proved that soil pH is the primary control of soil enzyme activity as evidenced by the fact that all the activities of tested soil enzymes were correlated with soil pH but only some with soil organic matter and other ecosystem-scale factors (Sinsabaugh et al., 2008). Oxidative enzymes, i.e., phenol oxidase and peroxidase were found to be more sensitive to soil pH change than the hydrolytic ones and increased with soil pH (Sinsabaugh et al., 2008).

Soil oxidative enzymes have been considered as a proximate control for the decomposition of organic matter (Freeman et al., 2001a; Sinsabaugh et al., 2008). By regulating the concentration of soluble phenolics and in turn the activity of hydrolytic enzymes, soil phenol oxidase has been proposed as an 'enzymatic latch' to hold soil organic C in oxygen-limited ecosystems such as peatlands (Freeman et al., 2001a). A positive relationship between phenol oxidase activity and organic C loss has also been found in some upland ecosystems (Carreiro et al., 2000; Sinsabaugh et al., 2002; Waldrop et al., 2004; Moorhead and Sinsabaugh, 2006). Taken together, it appears that soil pH regulation on organic matter decomposition and thus soil C storage is fundamentally through its control on the activity of soil oxidative enzymes.

Nitrogen fertilization may have profound impacts on below-ground decomposers, such as by modifying microbial community composition and thus the production of soil enzymes involved in the depolymerization of soil organic matter and plant litter (Fog, 1988; Berg and Matzner, 1997; Saiya-Cork et al., 2002; DeForest et al., 2004; Gallo et al., 2004). An increase in soil N availability may suppress the activity of oxidative enzymes, but stimulate the activity of cellulolytic enzymes such as soil cellulase (Fog, 1988; Berg and Matzner, 1997; Waldrop et al., 2004). As a consequence, N effect on decomposition depends on the chemical composition of organic matter (Sinsabaugh et al., 2002). To date, positive, negative, and neutral effects of N fertilization on soil C sequestration have been reported for ecosystems including Alaska tundra, alpine meadow, and northern hardwood forests (Neff et al., 2002; Mack et al., 2004; Waldrop et al., 2004). Given the large acreage planted to turf, the potential for substantial C sequestration therein, and that N-containing fertilizers are applied frequently, it is important to understand the role of N fertilization in soil C cycling in this ecosystem.

We hypothesize that N fertilization to the well-established turfgrass ecosystem would have minor impacts on the decomposition of grass clippings and soil organic matter. Instead, soil pH may greatly affect the decomposition of soil organic matter since an appropriate pH is required for catalytic functions of soil enzymes. The working hypothesis will be examined via quantifying potential activities of phenol oxidase, cellulase, chitinase, β-glucosidase, and N-acetyl-glucosaminidase and their relations with soil C and N mineralization. Since intermediate products of enzymatic reactions can provide additional information on soil C processes (Huang et al., 1998; Waldrop and Zak, 2006), we also analyzed soluble soil organic compounds. Our previous work showed that soil and microbiological characteristics varied with the ages of turfgrass systems (Shi et al., 2006a,b; Yao et al., 2006). Accordingly, two chronosequences of turfs with contrasting soil pH (i.e., acidic versus alkaline) were used in this study.

## 2. Materials and methods

### 2.1. Study sites and soil sampling

Two chronosequences of golf courses were used to examine the impacts of soil pH, mineral N input, and grass clipping addition on the decomposition of soil organic matter. The first study site, located in north Las Vegas, NV, consisted of three golf courses planted in 2000, 1987, and 1962, making them 6, 19 and 44 years old at the time of sampling, respectively. Each was established from native shrub-dominant desert land. The three desert golf courses were located 5–9 km from each other, with soil textures classified similarly as sandy loam. The second study site consisted of four golf courses in Pinehurst, NC. These courses were constructed in 2001, 1996, 1979 and 1907, making them 5, 10, 27, and 99 years old at the time of sampling, respectively. Each was established on land that was partially cleared off the native pine-dominant forest. The four NC golf courses were all within several km of each other and had similar or identical soils (sand or loamy sand). All golf courses were professionally managed to high standards. Each received annual split applications of N totalling 150–200 kg N $ha^{-1}$ $y^{-1}$ during the past 20 years. Turfgrasses were also fertilized with phosphorus (P) and potassium (K), and treated with pesticides as needed. Golf courses in NC were also limed to maintain soil pH.

All golf courses except the youngest desert course were planted to hybrid bermudagrass (*Cynodon dactylon* × *Cynodon transvaalensis*), a warm-season perennial, and overseeded in the fall with perennial ryegrass (*Lolium perenne* L.) to provide a temporary green canopy during the period of bermudagrass dormancy. The youngest desert course was also planted to perennial ryegrass.

Soils were sampled from the fairways of golf courses and from native, unplanted local comparison areas in both study sites in March 2006. Shrubs in the desert site were sparse; therefore the soils were sampled adjacent to, and 2–3 m away from the shrubs. Accordingly, the desert soil samples were collected from five locations identified as bare, shrub, 6-y turf, 19-y turf, and 44-y turf, and NC soil samples were collected from five locations identified as pine, 5-y turf, 10-y turf, 27-y turf, and 99-y turf.

Three fairways or sub-sites were chosen randomly from each golf course or the local comparison areas and used as the experimental replicates. From each replicate, eight soil cores (5 cm diameter × 7.5 cm length) were taken randomly, placed in ice-cold coolers, transported to the lab, and then mixed to form a composite sample. Soil was sieved (<4 mm), cleaned of most roots and grass residue, and stored at 4 °C prior to analyses.