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The extent and pathways of nitrogen loss in turfgrass systems: Age impacts

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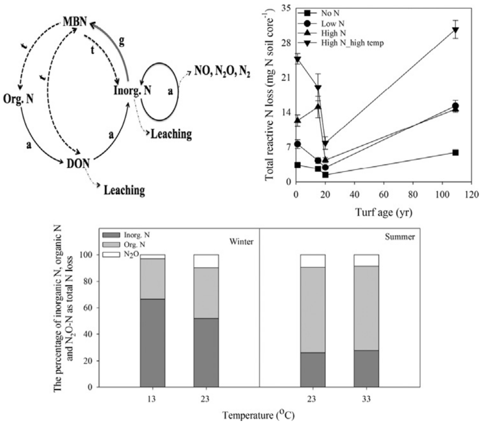
HIGHLIGHTS

- Total reactive N loss varied with turf age and showed a time delineated cup pattern.
- Dissolved organic N (DON) leaching was a dominant pathway of N loss from turfs.
- Proportional loss among reactive N species was affected by season and temperature.
- Seasonal variations of C availability reacted to temperature to affect N loss pathways.

GRAPHICAL ABSTRACT

Turf, including athletic fields, parks, golf courses and home lawns, is a popular urban and suburban land cover in the world for aesthetic and recreational purposes. Its acreage surges continuously with rapid global urbanization, and mitigating N loss from turf will remain a challenge and a goal. While microbial growth efficiency (g), turnover (t), and activity (a)-mediated organic matter degradation could all regulate the pool size of soil soluble N and therefore the loss of reactive N from turf, their trends over time differed. The combined effects led to a time delineated cup-shaped pattern of reactive N loss from turf. Seasonal variations of carbon and nutrient availability reacted to temperatures to affect extent and pathways of reactive N loss.



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ABSTRACT

Nitrogen loss from fertilized turf has been a concern for decades, with most research focused on inorganic (NO_3^-) leaching. The present work examined both inorganic and organic N species in leachate and soil N_2O emissions from intact soil cores of a bermudagrass chronosequence (1, 15, 20, and 109 years old) collected in both winter and summer. Measurements of soil N_2O emissions were made daily for 3 weeks, while leachate was sampled once a week. Four treatments were established to examine the impacts of fertilization and temperature: no N, low N at 30 kg N ha^{-1}, and high N at 60 kg N ha^{-1}, plus a combination of high N and temperature (13 °C in winter or 33 °C in summer compared to the standard 23 °C). Total reactive N loss generally showed a “cup” pattern of turf age, being lowest for the 20 years old. Averaged across all intact soil cores sampled in winter and summer, organic N leaching accounted for 51% of total reactive N loss, followed by inorganic N leaching at 41% and N_2O-N efflux at 8%. Proportional loss among the fractions varied with grass age, season, and temperature and

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fertilization treatments. While high temperature enhanced total reactive N loss, it had little influence on the partitioning of loss among dissolved organic N, inorganic N and N_2O-N when C availability was expected to be high in summer due to rhizodeposition and root turnover. This effect of temperature was perhaps due to higher microbial turnover in response to increased C availability in summer. However when C availability was low in winter, warming might mainly affect microbial growth efficiency and therefore partitioning of N. This work provides a new insight into the interactive controls of warming and substrate availability on dissolved organic N loss from turfgrass systems.

1. Introduction

Nitrogen is the most limiting nutrient for plant growth in terrestrial ecosystems and thus increased N input often leads to increase in plant biomass and yields (Conant et al., 2013). Over the past 50 years, synthetic N application has increased by ~10 fold from ~12 Tg yr^{-1} in the 1960s to ~100 Tg yr^{-1} in the 2000s (Fields, 2004; Mulvaney et al., 2009; Tilman et al., 2001), and this trend is unlikely to change. It is undeniable that fertilizer N helps support an increasing world population (Mulvaney et al., 2009; Tilman et al., 2001), but this benefit comes at a cost. On a worldwide scale, fertilizer N recovery efficiency (i.e., N in harvested plant biomass per N input) has remained <50% (Bouwman et al., 2005; Conant et al., 2013), implying that a sizable amount of N is potentially free to move through the environment – soil, water, and air. Indeed, reactive N in the environment has increased steadily since the 1960s and its negative impacts on natural resources, human health, and ecosystem services are broadly recognized (Fields, 2004; Vitousek et al., 1997; WHRC, 2007). Society is aware that controlling N loss from an ecosystem is crucial for sustaining the environment, and yet questions about how to effectively accomplish this control remain.

Turfgrass, planted on athletic fields, parks, golf courses, and home lawns, is popular for both aesthetic and recreational purposes. According to Milesi et al. (2005), turfgrass in the USA is the largest single 'crop' and occupies roughly 1.9% of the total land. There are a variety of grass species available, including C_3 (cool-season) and C_4 (warm-season) grasses, but essentially all require relatively high fertility (up to 200–300 kg N ha^{-1}) to maintain health and facilitate recovery from damage (Carey et al., 2012). Concerns have been raised for decades that such high amounts of N must certainly result in considerable loss, especially via leaching of inorganic N. Investigations designed to examine fertilizer N use efficiency in turf systems, typically employing either a mass balance approach or the use of ^{15}N, have reported that N recovery in grass clippings was moderate (De Nobili et al., 1992; Henning et al., 2013; Miltner et al., 1996; Raciti et al., 2008); and yet most data indicate fairly low amounts of inorganic N leaching from turf (Frank et al., 2005; Miltner et al., 1996; Raciti et al., 2008).

Because turf systems accumulate considerable soil organic N over time (Shi et al., 2006b), it is logical that mineralization would supply more N in older vs. younger turf. As predicted by the N-retention hypothesis – a principle underlying biological controls on inorganic N loss (Vitousek and Reiners, 1975), ecosystem N conservation will surge over time until it hits a steady state, and from this point of succession forward, within-system N will likely provide sufficient available N to support biotic growth. Based on this hypothesis, N applied at a constant rate may lead to high rates of N loss during the early development of a turf when the capacity for biotic N retention via plants and microbes is relatively small, and during the late development of turf when internal N supply is large. Although turfgrass growth will vary depending on management inputs (Milesi et al., 2005), soil organic matter accumulates rapidly during the first 20–30 years after turfgrass establishment and thereafter slows down markedly towards a steady state (Bandaranayake et al., 2003; Carley et al., 2011; Milesi et al., 2005; Qian and Follett, 2002). Thus, "young turf" (i.e., <20–30 years) has been deemed as a sink of external N input, whereas "the old turf" may receive sufficient inorganic N via mineralization and thus any additional fertilizer N would be more subject to significant loss (Petrovic, 1990). Zhang et al. (2013) reported that Kentucky bluegrass turf in Colorado changed from a sink to a weak source of greenhouse gas emission 20–30 years after establishment; by gradually reducing the rate of N fertilization as turf aged, N_2O emissions could be reduced ~40% compared to N fertilization at a constant rate of 150 kg N ha^{-1} yr^{-1}. Bremer (2006) also reported that low N application (50 kg N ha^{-1} yr^{-1}) reduced N_2O loss 63% compared to high N (250 kg N ha^{-1} yr^{-1}). It should be noted that some consider that turfgrasses, regardless of age, will always require some fertilizer N, because constant N leaking through harvest and cycling processes restricts ecosystem N conservation, causing N limitation even after the steady state (Neff et al., 2003; Vitousek et al., 1998). Therefore, a better understanding of N leaking pathways and their regulation modes, specifically in pertaining to turf of different ages, may help prevent excessive N loss.

Nitrate leaching has long been emphasized as the primary route of N loss from turf, leading to eutrophication and acidification of water body (Flipse et al., 1984; Geron et al., 1993; Keeney and Olson, 1986; Petrovic, 1990). However, a growing body of evidence from natural and agricultural ecosystems suggests that organic N runoff and leaching must be considered when assessing the total N loss from an ecosystem (Christou et al., 2005; Murphy et al., 2000; Perakis and Hedin, 2002; Siemens and Kaupenjohann, 2002; Van Kessel et al., 2009). A 22-month lysimeter study showed that 25 to 78% of N leached from a turfgrass system was in the organic form (Barton et al., 2009). By examining 17 bermudagrass systems, Lu et al. (2015) also showed that water- and salt solution-extractable soil organic N was comparable to soil inorganic N, implying that N leaching or runoff via organic form could be as high as inorganic species.

Soil N_2O efflux has received considerable attention due to N_2O potent effects on global warming and ozone depletion (IPCC Climate Change, 2007; Ravishankara et al., 2009). The U.S. EPA reported that roughly 79% of total anthropogenic N_2O emissions in the USA are from the soil and systems under management (U.S.EPA, 2016). Fertilized turf may be an important source of atmospheric N_2O (Bremer, 2006; Groffman et al., 2009; Li et al., 2013; Maggiotto et al., 2000). As shown by Kaye et al. (2004), turf contributed 30% of N_2O emissions in a studied region where it occupied only 6.4% of the total land area. So far, most investigations on N loss from lawn have centered on individual processes and control factors. While simultaneous measurements of N loss via leaching and gas emissions can help better identify the major pathway of N loss and associated biotic and abiotic controls, systematic data collection is lacking.

Given rapid global urbanization and the concurrent rise in turfgrass acreage, mitigating N loss from turf remains a challenge and a goal. Although there is no easy solution for N efflux, the knowledge gained from natural ecosystems – forests and grasslands, suggests that the degree of biotic N retention as well as ecosystem N leak must be taken into account when designing an environmentally sound N fertilization program. We used a turfgrass chronosequence, and specifically three events or conditions (grass dormancy versus active growth; seasonal change in temperature; fertilization regime with zero fertilization versus fertilization at low and high rates) to address the fundamental question, how does turf age affect the extent and pathways of N loss?