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Evaluation of nitrogen and phosphorus transport with runoff from fairway turf managed with hollow tine core cultivation and verticutting ☆

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HIGHLIGHTS

- We compared runoff from turf managed with hollow tines (HT) or HT and verticutting.
- We hypothesized verticutting would further reduce fertilizer transport with runoff.
- Alteration of risk associated with changes in management practices was not observed.
- Water quality limits for phosphorus were exceeded in ponds receiving the turf runoff.
- Levels of nitrogen in a pond receiving runoff were below surface water standards.

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ABSTRACT

Enrichment of surface waters with excess nutrients is associated with increased algal blooms, euthrophication and hypoxic zones, as reported in the northern Gulf of Mexico. A source of nutrients to surface waters results from fertilizer runoff. Management strategies used to maintain turf on golf courses and recreational fields often include aerification and application of fertilizer. Although research exists on benefits of core cultivation and verticutting (VC) to reduce thatch and the transport of applied chemicals with runoff, there are no studies reporting the effect of coupling these management practices with the goal of further reduction of off-site transport of fertilizer with runoff. We hypothesized that the addition of VC to hollow tine core cultivation (HTCC) would enhance infiltration of precipitation, reduce runoff and nutrient transport with runoff and therefore influence concentrations of nutrients in surface waters receiving runoff from turf managed as a golf course fairway. Greater runoff and mass of soluble phosphorus and ammonium nitrogen transported with runoff were measured from plots managed with HTCC + VC than HTCC; however, the reverse was noted for nitrate nitrogen. Only a portion of the observed trends proved to be statistically significant. Our research showed no reduction or enhancement of risk associated with surface water concentrations of phosphorus or nitrogen, resulting from runoff from creeping bentgrass turf that was managed with HTCC + VC compared to HTCC. Data obtained in this research will be useful to grounds superintendents when selecting best management practices and to scientists seeking data relating runoff to land management for watershed-scale modeling.

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1. Introduction

Managed turf is found in both public and private settings; in parks and cemeteries, along road sides and right-of-ways, as residential and commercial lawns, as sod farms, and on athletic fields and golf courses. In the United States an estimated 16 million hectares of land is covered by tended lawn (Milesi et al., 2005). There are an estimated 35,000 golf courses worldwide with the approximately 17,000 golf courses in the United States, more than 2,300 golf courses in either Canada, the United Kingdom or Japan, and approximately 1,500 golf courses in Australia (Saito, 2010).

Nitrogen and phosphorus are important plant nutrients that are often applied to highly managed biotic systems, including golf course turf. Approximately one-third of a typical golf course is comprised of fairways (Lyman et al., 2007; Watson et al., 1992). Runoff from golf course fairways may contribute to the degradation of water quality in surrounding surface waters depending on the quantity of runoff and level of contaminants. Shuman (2002) observed that the mass of phosphorus in runoff from golf course fairway turf was directly related to the

Abbreviations: (HTCC), hollow tine core cultivation; (NCC), no core cultivation; (STCC), solid tine core cultivation; (VC), verticutting.

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fertilizer rate with the initial runoff event containing the majority of the transported phosphorus. King et al. (2001) observed storm runoff from a golf course in Texas contributed an estimated 2.3 kg ha^{-1} of nitrate and nitrite nitrogen and 0.33 kg ha^{-1} of orthophosphate to a stream during a 13-month period.

The presence of excess nutrients in surface waters may be harmful to lake biota and human health when at levels that produce undesirable consequences such as eutrophication or harmful algal blooms (Correl, 1998; Lake Scientist, 2012). In addition, nitrate has been suspected to be an ecologically relevant endocrine disruptor that can alter hormone regulation, causing morphological abnormalities (Guillette and Edwards, 2005). When found in drinking water, nitrate exposure may result in methemoglobinemia, a potentially lethal condition known as blue baby syndrome (Knobeloch et al., 2000; United States Environmental Protection Agency, 1986). To combat these concerns, water quality guidelines have been proposed to limit phosphorus and nitrogen concentrations in surface waters. For example, criteria have been established to limit total phosphorus concentrations to 0.025 mg L^{-1} within lakes or reservoirs, 0.05 mg L^{-1} in streams draining into lakes or reservoirs and 0.1 mg L^{-1} in streams or flowing waters not directly discharging into lakes or reservoirs (Schindler, 1977; United States Environmental Protection Agency, 1986). Nitrate nitrogen water quality standards have recently been proposed for surface waters that support aquatic life and recreation (class 2). These draft standards are based on aquatic life toxicity test reported in the scientific literature and completed by the by the U.S. Environmental Protection Agency. The acute standard (maximum concentration at any time) has been set at 41 mg L^{-1} NO_3–N. Chronic standards (four day average concentrations that can not be exceeded more than once in a three year period) have been set at 3.1 mg L^{-1} NO_3–N (class 2A — cold water community) and 4.9 mg L^{-1} NO_3–N (class 2B — cool-warm water community); levels that are more restrictive than the existing drinking water standard for human health set at 10 mg L^{-1} NO_3–N (United States Environmental Protection Agency, 1986; Monson, 2010; MPCA, 2010).

Recreational fields and golf courses and are subject to foot and vehicle traffic; resulting in turf wear, soil compaction and reduced water infiltration (Dunn et al., 1995; Baldwin et al., 2008). These green spaces are often managed to alleviate surface compaction, enhance water penetration, stimulate root and shoot growth and control thatch (Barton et al., 2009; Beard, 1973; Callahan et al., 1998; Carrow et al., 1987; Dunn et al., 1995; Rowland et al., 2009; Turgeon, 1985; Vargas and Turgeon, 2004; White and Dickens, 1984). While thatch is beneficial to enhance turf durability, moderate soil temperatures and lessen weed invasion, an excessive thatch-mat can increase disease and pest pressure, lessen cold temperature tolerance, and reduce water infiltration and hydraulic conductivity (Beard, 1973; White and Dickens, 1984; Murray and Juska, 1977; Harris, 1978; Miller, 1965). Verticutting (VC) and core cultivation are two management practices used to remove excess thatch on sports fields and golf course fairways and putting greens (Barton et al., 2009; Stier and Hollman, 2003). Core cultivation with hollow tines (HTCC) removes cores from the turf, which are deposited on the turf surface and allowed to air-dry before the soil is brushed back into the open holes and the extracted thatch is removed. Verticutting uses rotating blades to slice into the turf to remove dead plant material and thatch, promoting new turf growth and preparing seedbeds for overseeding. Core cultivation or verticutting of turfgrass promotes water conservation as these management strategies increase water movement into the turfgrass root zone; resulting in greater infiltration of rainfall, enhanced rooting depth that reduces water leaching beyond the root zone, and healthier turf that requires less water and need for pest control (Waltz, 2007). The frequency of these practices (two to three times a year or as often as every 10 days) and their associated cost will vary with turfgrass species and weather conditions, as they are typically performed when the turfgrass is growing and not under stress (e.g. spring and fall) (Torisello, 2007).

Evaluation of runoff and the transport of nutrients, plant protection products and soil with runoff has been documented around the world at multiple scales; including plot-, field-, watershed- and catchment-scale monitoring and modeling (Cohen et al., 1999; Soulsby et al., 2004; Nash et al., 2005; Xu et al., 2007; Bakri et al., 2008; Vadas et al., 2008; Thomaz and Vestena, 2012; Donn et al., 2012; Pärn et al., 2012). For example, in Australia, moderate to high levels of nitrogen and phosphorus were measured in a catchment with noted increases in nutrients occurring as the stormwater passed through the urban areas (Bakri et al., 2008). A modeling assessment of runoff in a watershed in Brazil showed adoption of conservation practices that increased water infiltration would reduce runoff and total nitrogen and total phosphorus transported with the runoff (Rocha et al., 2012). Plot- and field-scale research has documented the influence of management and cultural practices on runoff and chemical transport with runoff from highly managed biotic systems, including turfgrass (Wauchope et al., 1990; Cole et al., 1997; Kauffman and Watschke, 2007; Rice et al., 2010; Rice and Horgan, 2011; Rice et al., 2011) and agricultural crops (Hansen et al., 2001; Potter et al., 2004; Rice et al., 2007). In addition, reduced surface runoff has been observed from turfgrass compared to tilled soils (Gross et al., 1990) and from creeping bentgrass (*Agrostis palustris* Huds.) turf relative to perennial ryegrass (*Lolium perenne* L.) turf (Linde et al., 1995). Documenting and adopting practices that reduce the off-site transport of nutrients and pesticides with overland flow or runoff will help maintain plant nutrient or protection products at their site of application, therefore enhancing efficacy while reducing contamination and unintended affects in adjacent areas.

The objective of the present study was to identify which cultural practice, hollow tine core cultivation (HTCC) or HTCC with verticutting (HTCC+VC), maximizes phosphorus and nitrogen retention at the site of fertilizer application, thereby maintaining turf quality while minimizing adverse environmental effects associated with the off-site transport of nutrients. Edge-of-plot runoff and the concentration of soluble phosphorus (sol-P), ammonium nitrogen (NH_4–N), and nitrate nitrogen (NO_3–N) in the runoff were measured to determine the mass load of nutrients transported with runoff. Estimated environmental concentrations of phosphorus and nitrogen in a surface water receiving runoff from turf were calculated using our plot load data and reported runoff area and pond volumes measured at a local golf course. These surface water concentrations were compared with water quality criteria to determine which management practice is most efficient at mitigating environmental risk.

2. Materials and methods

2.1. Turf plots, runoff collection system and rainfall simulator

Experiments were conducted at the University of Minnesota (Saint Paul, MN, USA) on turf plots (6 plots; individual plot size: 148.8 m^2, 24.4 m length × 6.1 m width) managed as a golf course fairway. *A. palustris* Huds. (L-93 creeping bentgrass) covered Waukegan silt loam (3% organic carbon, 29% sand, 55% silt, and 16% clay) that was graded to a 4% slope running east to west. Runoff collection systems, described in detail elsewhere (Rice et al., 2010), were constructed at the western edge of each plot. In short, stainless steel flashing guided runoff from each turf plot into a polyvinyl chloride (PVC) gutter which led to a stainless steel trapezoidal flume (Plasti-Fab, Tualatin, OR, USA) equipped with bubble tube and sample collection ports. Gutter covers and flume shields prevented dilution of runoff with precipitation.

A rainfall simulator, modified from the design of Coody and Lawrence (1994), was constructed to delivered precipitation with a droplet size spectrum and impact velocity similar to natural rainfall. The base of the simulator surrounded two plots and guided water to eighteen risers equipped with a pressure regulator (Lo-Flo, 15 psi), nozzle (No. 25) and standard PC-S3000 spinner (Nelson Irrigation, Walla Walla, WA, USA) suspended 2.7 m above the turf. Specific details of the rainfall simulator are published elsewhere (Rice et al., 2010).