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TURFGRASS AND ENVIRONMENTAL RESEARCH ONLINE

USING SCIENCE TO BENEFIT GOLF

Plot studies were conducted at the University of Minnesota to determine which core cultivation practice, solid tine or hollow tine, was more successful at reducing losses of phosphorus and nitrogen with runoff from creeping bentgrass (*Agrostis stolonifera* L.) turf managed as a golf course fairway. Measured quantities of nutrients in the edge-of-turf runoff and characteristics of a local golf course were used to calculate nutrient concentrations in a surface water receiving runoff from managed turf. Surface water concentrations of phosphorus and nitrogen were compared to water quality criteria and drinking water standards to evaluate which core cultivation practice would be more effective at reducing environmental risk.

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PURPOSE

The purpose of *USGA Turfgrass and Environmental Research Online* is to effectively communicate the results of research projects funded under USGA's Turfgrass and Environmental Research Program to all who can benefit from such knowledge. Since 1921, the USGA has funded more than $40 million for research at universities. The private, non-profit research program provides funding opportunities to university faculty interested in working on environmental and turf management problems affecting golf courses. The outstanding playing conditions of today's golf courses are a direct result of ***using science to benefit golf***.

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Solid or Hollow: Which Core Cultivation Method is the Most Effective at Reducing Nutrient Loss with Runoff from Turf?

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SUMMARY

Excess nutrients in surfaces waters can result in undesirable consequences. Experiments were designed to quantify phosphorus and nitrogen transport with runoff from plots maintained as a golf course fairway to identify which cultural practice, solid tine or hollow tine core cultivation, will maximize nutrient retention at the site of application and reduce nutrient concentrations in adjacent surface waters. The study found:

- Runoff volumes and amounts of ammonium nitrogen, nitrate nitrogen, and soluble phosphorus transported with runoff were less from turf managed with hollow tines than solid tines.
- Concentrations of nitrogen in a surface water receiving runoff from turf, managed with either solid tines or hollow tines, were below the drinking water standard for nitrate nitrogen (10 mg L^{-1}) and levels associated with increased algal growth (1 mg L^{-1}).
- Only surface water concentrations associated with hollow tine core cultivation 2 days prior to runoff displayed concentrations of phosphorus below the water quality criteria to limit eutrophication in streams draining into lakes and reservoirs (0.05 mg L^{-1}).
- Regardless of the cultivation practice, concentrations of phosphorus in a surface water receiving turf runoff exceeded levels associated with increased algal growth and eutrophication within a lake or reservoir (0.025 mg L^{-1}).

The increased occurrence of nuisance algal blooms, reported eutrophication of surface waters, and the presence of a hypoxic zone in the northern Gulf of Mexico has heightened concern regarding the sources of excess nutrients to surface waters (4, 10, 27, 35, 41; http://toxics.usgs.gov/hypoxia/hypoxic_zone.html). To control eutrophication, the United States Environmental Protection Agency (USEPA) has established water quality criteria that limit total phosphorus concentration 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 (32, 40). Drinking water standards have also been set at 10 mg L^{-1} for nitrate nitrogen to prevent methemoglobinemia in infants, a potentially lethal condition known as "blue baby syndrome" (18, 40). More recently, nitrate has been suspected to be an ecologically relevant endocrine disruptor that may alter hormone regulation and result in abnormalities (14).

Nitrogen and phosphorus are important plant nutrients that are often applied to highly managed biotic systems such as golf courses, commercial landscapes, and agricultural crops. Dissolved, suspended, or particulate-bound contaminants can be transported with surface runoff (31, 42). The off-site transport of phosphorus in runoff from croplands tend to favor movement with soil particles, whereas the dissolved forms are favored in runoff from turf, as sediment loss is typically insignificant (36, 42). Shuman (37) observed that the mass of phosphorus in runoff from golf course fairway turf was directly related to the fertilizer rate with the initial runoff event containing the majority of the transported phosphorus.

Fairways comprise approximately one-third the managed turf of a typcial golf course (21, 42), which may be adjacent to surface waters. Therefore 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.

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Figure 1. Creeping bentgrass turf managed with solid tine (A) or hollow tine (B) core cultivation. Cores removed with the hollow tines (pictured above in B) were air dried and worked back into the turf with a leaf rake. Turf and thatch that remained on the surface were removed with a back-pack blower prior to fertilizer application and runoff events.

Reduced surface runoff has been observed in turf compared with tilled soils (13), and creeping bentgrass (*Agrostis stolonifera* L.) maintained as a golf course fairway has been shown to reduce surface runoff compared to perennial ryegrass (*Lolium perenne* L.) (19). However, golf courses have also been shown to contribute to increased nutrient loads in receiving surface waters. King et al. (16) observerd storm runoff from a golf course in Texas that 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.

Golf courses and recreational fields are subject to foot and vehicle traffic that cause soil compaction and turf wear, reducing water infiltration and increasing turf stress (1, 11). Golf course fairways and putting greens are often managed with core cultivation during the spring and fall to alleviate surface compaction, enhance water infiltration, control thatch, and stimulate root and shoot growth (2, 3, 5, 7, 11, 23, 24, 39, 43). Solid tine core cultivation requires a reduced amount of labor and is less disruptive to the surface of the turf but is believed to cause localized compaction (26). Cultivation with hollow tines typically involves removing cores from the turf, which are air-dried and brushed back into the open holes (26).

The overall objective of the present study was to identify which cultural practice, solid tine or hollow tine core cultivation, maximizes nitrogen and phosphorus retention at the site of fertilizer application, thereby maintaining turf while minimizing adverse environmental effects associated with the off-site transport of nutrients. Runoff volume and the mass of ammonium nitrogen, nitrate nitrogen and soluble phosphorus transported with runoff from fairway turf were measured. Characteristics of a local golf course (area of fairway turf contributing runoff to an adjacent surface water of known volume) were used to extrapolate edge-of-plot runoff data to surface water concentrations that were compared with water quality criteria to determine which core cultivation practice was more efficient at mitigating environmental risk.

Site Description

Experiments were performed on turf plots (plot size: 24.4 m length x 6.1 m width, 6 plots) managed as a golf course fairway (height of cut: 1.25 cm, three times weekly, clippings removed; topdressed: 1.6-mm depth of sand, weekly) at the University of Minnesota Turf Research, Outreach and Education Center (Saint Paul, MN). The site is comprised of Waukegan silt loam (3% organic carbon, 29% sand, 55% silt, and 16% clay) with a natural slope running east to west that was graded to 4%. Creeping bentgrass ('L-93') sod was installed 14 months prior to initiation of the reported runoff studies.

Core Cultivation

Plots were aerated with either solid tines (0.95-cm diameter x 11.43-cm depth with 5-cm x 5-cm spacing) or hollow tines (0.95-cm internal diameter x 11.43-cm depth with 5-cm x 5-cm spacing) on June 21 and September 28 (Figure 1). Cores removed with the hollow tines were air dried and worked back into the turf. Turf and thatch remaining on the surface were removed with a back-pack blower. Sand topdressing was not performed within a week of simulated precipitation or immediately following core cultivation.

Fertililzer Application and Simulated Precipitation

A rainfall simulator (9, 29) was constructed to deliver precipitation similar to storm intensities recorded in Minnesota during July through October (Figure 2). Two days prior to initiation of simulated precipitation, each plot was pre-wet with the maintenance irrigation beyond soil saturation to allow for collection of background samples and provide uniform water distribution across the plots.

Granular fertilizer containing 18% nitrogen (9.72% urea nitrogen, 0.63% ammoniacal nitrogen, 3.15% water insoluble nitrogen, 4.50% methylene urea), 3% available phosphate (P_2O_5), and 18% soluble potash (K_2O) was applied at label rates (136.5 kg/ha = 24.4 kg/ha N and 1.8

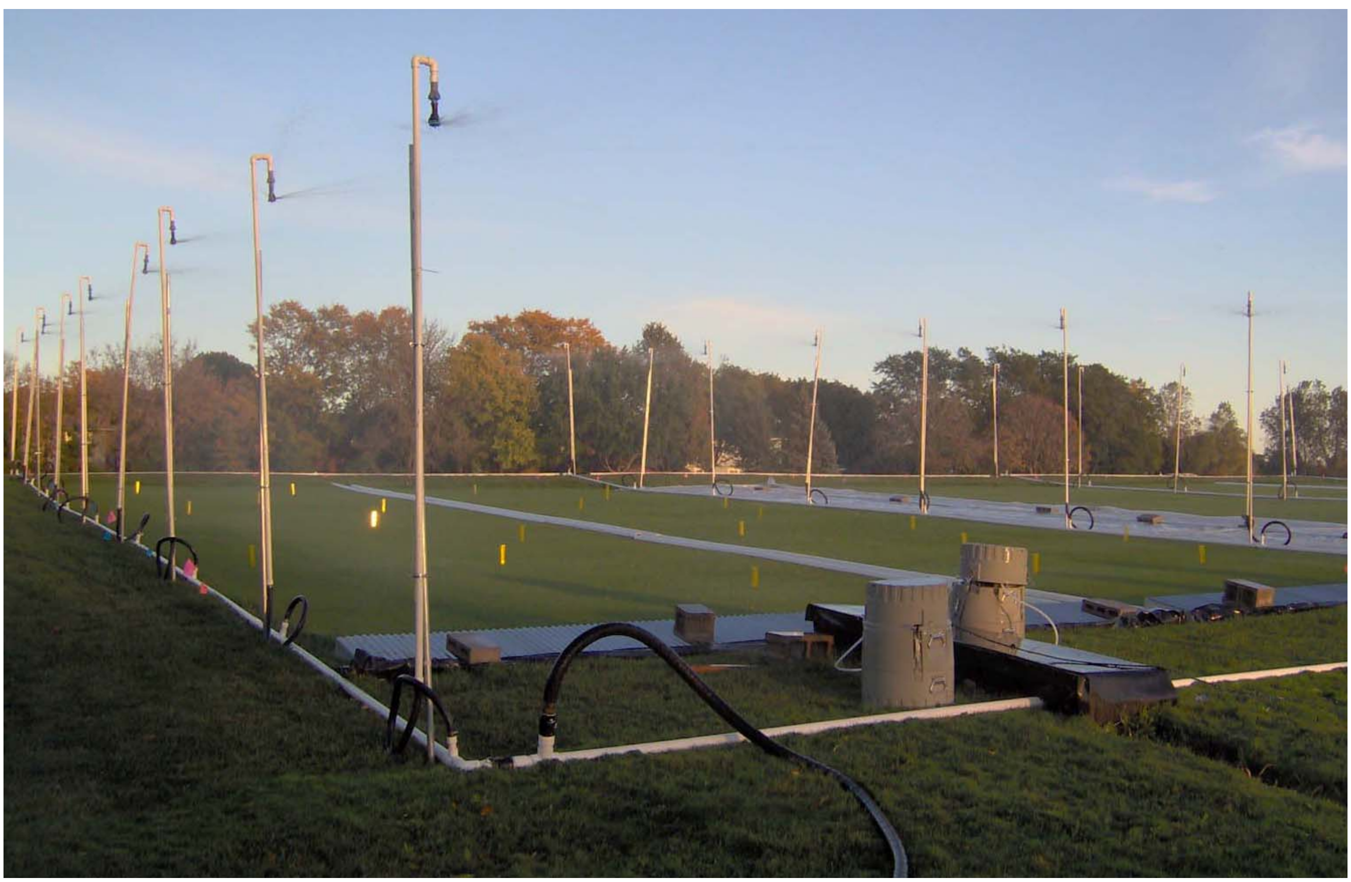

Figure 2. A rainfall simulator deliver precipitation resembling storm intensities recorded in Minnesota. Rain gauges distributed across the plots verified quantity and rate of precipitation.

Figure 3. Runoff collection gutters guided runoff from the turf to flumes equipped with automated samplers and flow meters. Gutter covers and flume shields prevented dilution of runoff with precipitation (shown in Figure 2).

kg/ha P; 121.5 lbs/acre = 21.7 lbs/acre N and 1.6 lbs/acre P) to all plots perpendicular to runoff flow, followed by brief irrigation (< 1 mm) with the maintenance irrigation system. Simulated precipitation was initiated 26 hours (± 13) after fertilizer application when soil moistures were at 46 % (± 7) water holding capacity. Petri dishes and rain gauges distributed across the plots verified fertilizer application rates and the quantity and rate of simulated precipitation.

Runoff Collection and Nutrient Analysis

Runoff collection systems, modified from the design of Cole et al. (8), were constructed at the edge of each plot to guide runoff from the turf to flumes equipped with automated samplers and flow meters (29, Figure 3). Water samples were removed from the automated samplers and stored frozen until laboratory analysis. Irrigation source water, background runoff water, and background runoff spiked with the applied fertilizer served as blank and positive control samples.

Water samples were analyzed for soluble phosphorus, ammonium nitrogen, and nitrate nitrogen. Soluble phosphorus was quantified from filtered water samples following standard methodologies for molybdenum blue reaction and spectrophotometric quantification (25, 35). Levels of ammonium nitrogen and nitrate nitrogen were determined by the diffusion-conductivity method involving the gaseous diffusion of ammonia across a gas permeable membrane in the presence of excess potassium hydroxide with subsequent conductivity detection (6).

Calculating Nutrient Concentrations in a Pond Receiving Turf Runoff

Nutrient loads (mg m^{-2}) in the edge-of-

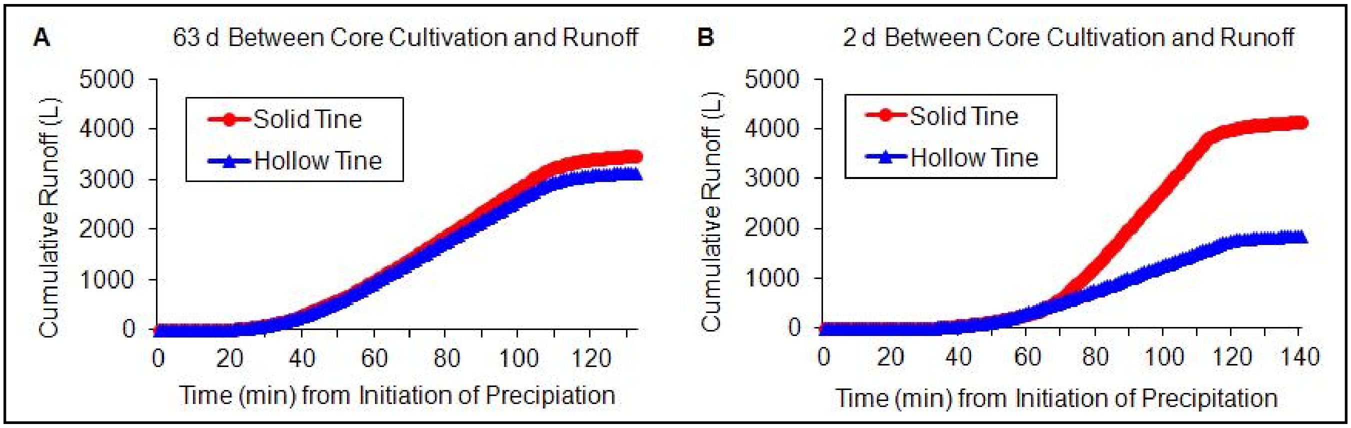

Figure 4. Cumulative volume of water measured as runoff from turf plots managed with hollow tine or solid tine core cultivation 63 days (A) and 2 days (B) prior to simulated precipitation and runoff.

plot runoff were calculated from recorded runoff volumes (L m^{-2}) and measured concentrations (mg L^{-1}) of soluble phosphorus, ammonium nitrogen, and nitrate nitrogen in the runoff. Nutrient concentrations in a body of water receiving the runoff was determined using characteristics of a golf course located less than 20 miles from our study site, including the volume (L) of a pond receiving runoff from a known area of the golf course (m^2) and considering the percentage of that area represented by fairway turf.

Estimated nutrient concentrations of the surface water receiving runoff from fairway turf managed with solid tine or hollow tine core cultivation were compared to water quality criteria and drinking water standards to evaluate which core cultivation practice would be more efficient at mitigating environmental risk. Detailed descriptions of the calculations are provided elsewhere (29).

Statistical Analysis

The rainfall simulator delivered precipitation to two plots simultaneously. Therefore a randomized complete block design was used to assign one of each core cultivation treatment to a block, providing three replicate side-by-side comparisons of solid tine and hollow tine core cultivation for each runoff event. Analyses of variance were performed to evaluate runoff volumes and nutrient loads, with core cultivation as the single criteria of classification for the data (38).

Reduced Runoff Volume with Hollow Tine Core Cultivation

Runoff experiments were initiated on August 23 and September 30, while the turf was actively growing (mean air temperatures: August 1-31 (71˚ F), September 1-30 (67˚ F)). In each event precipitation was terminated 90 minutes following the onset of runoff. Overall, runoff volumes were less from fairway turf plots managed with hollow tine core cultivation compared to solid tine core cultivation.

Although a delay in the construction of the rainfall simulator resulted in a variation of time between core cultivation and simulated precipitation for the two runoff events (63 days, 2 days), the trends observed in runoff volume between hollow tine and solid tine core cultivation were comparable. For example hydrographs displayed reductions in runoff volume from plots aerated with hollow tines compared to solid tines for more than 80% of the recorded data (n > 130). When cumulative runoff volumes were considered, plots receiving core cultivation 63 days prior to rainfall simulation demonstrated a 10% reduction with hollow tines compared to solid tines (Figure 4A). The same trends were observed and enhanced when plots received core cultivation 2 days prior to simulated rainfall resulting in a 55% reduction in cumulative runoff volume from hollow tine plots (Figure 4B). A smaller percentage of applied precipitation was measured as runoff from plots managed with hollow tines (28 to 36%) compared

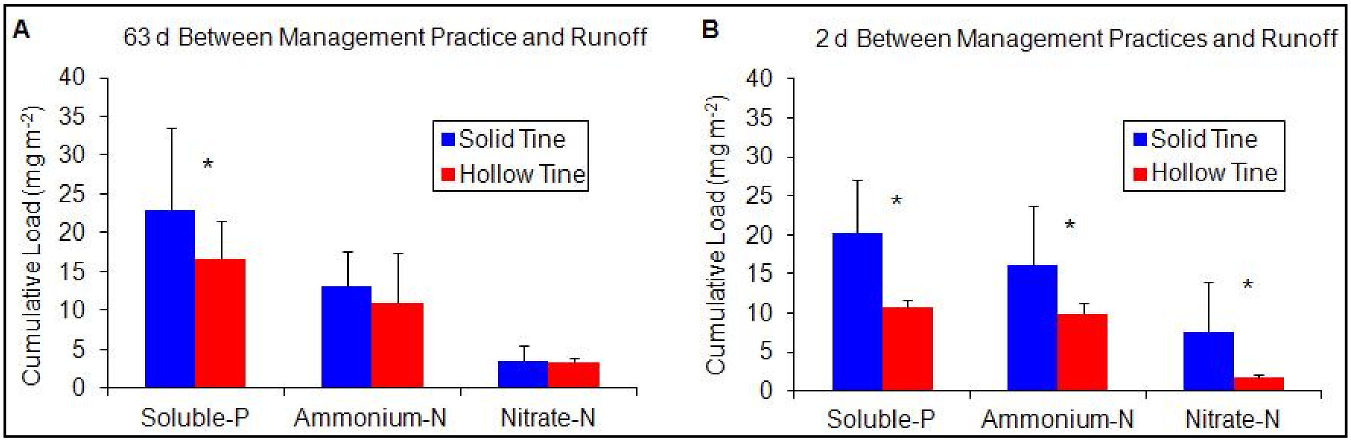

Figure 5. Mean cumulative load of soluble phosphorus, ammonium nitrogen and nitrate nitrogen measured in runoff from creeping bentgrass turf plots managed with solid tine or hollow tine core cultivation 63 days (A) and 2 days (B) prior to simulated precipitation and runoff. Fertilizer (18-3-18, % available nitrogen-phosphate-potash) was applied 26 hours (± 13) prior to simulated precipitation and runoff. Standard deviations of the means are presented as error bars. An asterisk represents statistical difference ($p < 0.05$) between the paired means.

to solid tines (41 to 62%), suggesting improved infiltration of precipitation with hollow tine core cultivation.

The greatest distinction in soil physical properties between plots managed with solid tines or hollow tines is most evident soon after cultivation and lessens with time as compaction dissipates, roots grow and holes are filled or covered. As a result, the greatest divergence in runoff volumes between treatments was observed at 2 days following cultivation compared to 63 days. Other researchers have reported greater air porosity and saturated water conductivity in turf managed with hollow tines compared to solid tines (26) and enhanced water infiltration in turf managed with hollow tine core cultivation compare to untreated turf (2, 23).

Reduced Nutrient Transport in Runoff with Hollow Tine Core Cultivation

Analysis of the source water applied as maintenance irrigation and simulated precipitation contained negligible levels of nutrients (less than 0.005 mg L^{-1}), which were subtracted from the results presented here. Soluble phosphorus, nitrate nitrogen and ammonium nitrogen were detected in the initial runoff sample and throughout the runoff events.

The quantity of nutrients transported with runoff from plots managed with solid tines exceeded that of plots managed with hollow tines. Plots receiving hollow tine core cultivation 63 days prior to runoff showed a 27%, 15%, and 5% reduction in cumulative loads of soluble phosphorus, ammonium nitrogen, and nitrate nitrogen, respectively (Figure 5A). Greater reductions in nutrient transport with runoff from turf managed with hollow tines compared to solid tines were observed 2 days following core cultivation with 47%, 39%, and 77% decline in cumulative loads of soluble phosphorus, ammonium nitrogen, and nitrate nitrogen, respectively (Figure 5B).

Analysis of nutrient loads with runoff volumes and nutrient concentrations revealed loads were attributed to runoff volume more than chemical concentrations for both core cultivation practices (volume r^2 = 0.66 to 0.89, concentration r^2 = 0.09 to 0.19). This greater association of chemical load with runoff volume explains, in part, the increased nutrient transport associated with the solid tine plots compared to hollow tine plots and the increased difference in nutrient loads between cultivation practices at 2 days compared to 63 days.

Solid tine core cultivation pushes the soil aside to create channels while hollow tine core cultivation removes cores and returns the soil

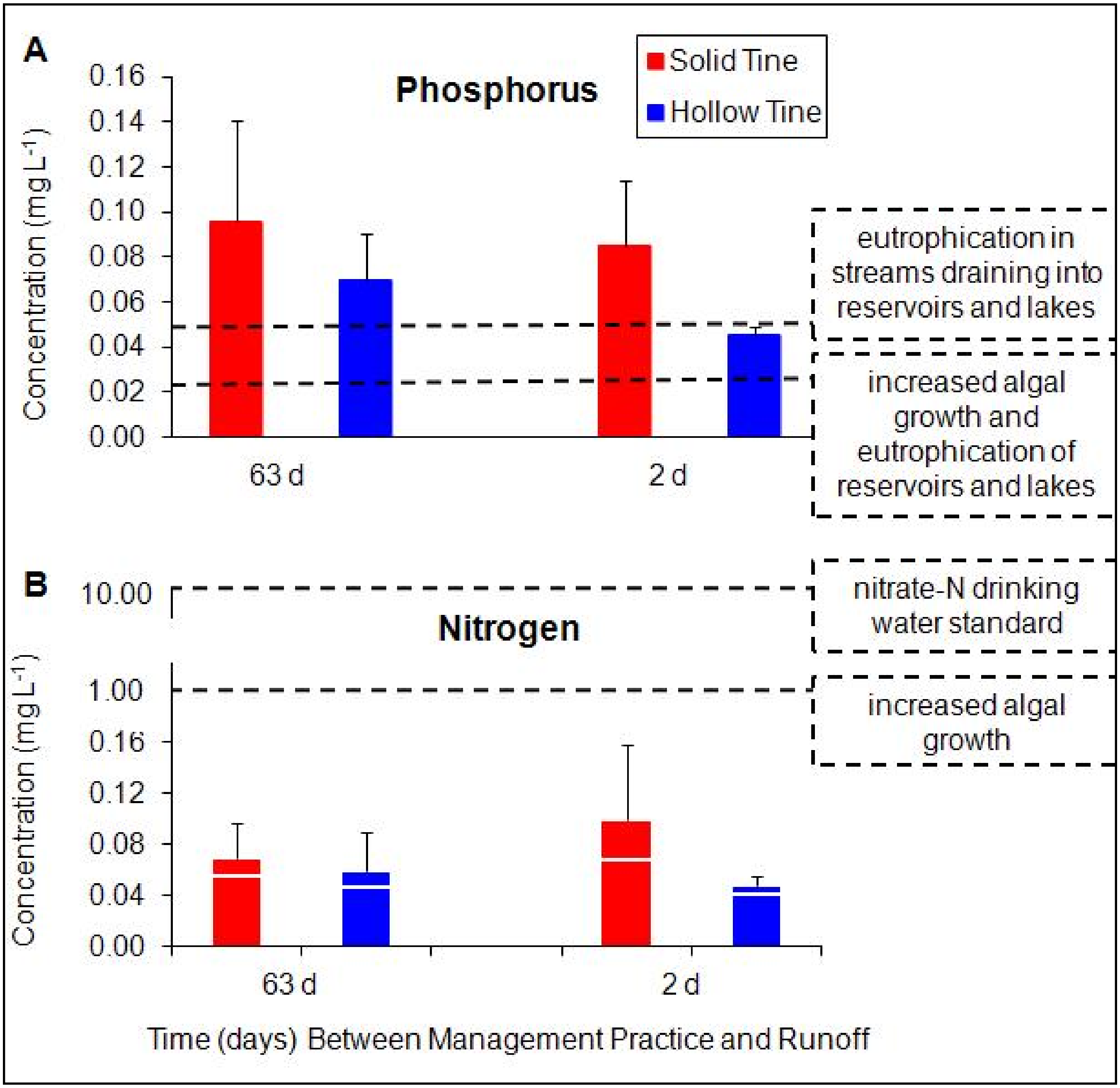

Figure 6. Estimated environmental concentrations of phosphorus (soluble phosphorus) (A) and nitrogen (ammonium nitrogen and nitrate nitrogen) (B) in a surface water receiving runoff from fairway turf managed with hollow tine or solid tine core cultivation 63 days and 2 days prior to runoff. The broken lines represent established water quality criteria and drinking water standards. Split bars in the nitrogen graph (B) represent nitrate nitrogen on top and ammonium nitrogen loads on the bottom.

back to the turf. Consequently one would anticipate increased accessibility of soil adsorptive sites with the hollow tine cultivation and greater soil compaction with the solid tine cultivation. This would influence availability of applied chemicals for transport (12, 20, 28) and infiltration and hydraulic conductivity as previously reported (2, 23, 26).

Effect of Cultivation on Nutrient Concentrations in Surface Waters

Estimated environmental concentrations of nutrients in a surface water receiving runoff from fairway turf managed with either solid tines or hollow tines resulted in 0.04 to 0.10 mg L^{-1} of soluble phosphorus, 0.04 to 0.07 mg L^{-1} of ammonium nitrogen, and 0.01 to 0.03 mg L^{-1} of nitrate nitrogen. When compared with water quality guidelines for phosphorus, only surface water concentrations associated with hollow tine core cultivation 2 days prior to runoff displayed concentrations of phosphorus below the U.S. EPA water quality criteria to limit eutrophication in streams draining into lakes and reservoirs (0.05 mg L^{-1}, Figure 6A).

Regardless of the cultivation practice, surface water concentrations of phosphorus exceeded levels associated with eutrophication within a lake or reservoir (0.025 mg L^{-1}) and increased algal growth (0.025 mg L^{-1}, 32, 40). In contrast, surface water concentrations of nitrogen were well below levels associated with increased algal growth (1 mg L^{-1}) and the drinking water standard for nitrate nitrogen (10 mg L^{-1}, 32, 40, 42, Figure 6B).

Although we observed a reduction in runoff volume and loads of nutrients with runoff from turf managed with hollow tine compared to solid tine core cultivation, the difference in estimated environmental concentrations associated with the cultivation practices did not result in drastic changes relative to water quality standards for algal growth or eutrophication (exception: soluble phosphorus, hollow tine, 2 days after aeration). This is in contrast to our previous observations with pesticides where, with a few exceptions, replacing solid tine core cultivation with hollow tine core cultivation resulted in surface water concentrations of the pesticides below levels of concern for the sensitive aquatic organisms evaluated (30).

The sensitivity of organisms to nitrate has been shown to vary greatly depending on the species and stage of development (15, 33). Metabolic effects have been observed with early or delayed metamorphosis of toad and frog tadpoles exposed to nitrate or nitrite, however, at levels well above the concentrations reported here (14, 22, 44). Disturbance of normal cell-to-cell interaction and function of the endocrine system can result from exposure of pollutants at relatively low concentrations. Scientists have reported potential endocrine disruption associated with exposure to nitrate, noting a significant inverse relationship between nitrate levels in lake water and plasma testosterone concentrations in juvenile alligators, warranting the need for further evaluation (14).

Studies have shown that mixtures of pollutants can result in additive, synergistic, or antagonistic effects (17). Evaluation of more sensitive toxicological endpoints, such as biomarkers associated with endocrine disruption and potential synergistic effects of nutrient and pesticide contaminants, may reveal benefits of hollow tine versus solid tine core cultivation in relation to nutrient transport to surface waters. However, this was beyond the scope of the current project. Overall understanding nutrient transport with runoff and identifying strategies that reduce off-site transport will increase the effectiveness of applied nutrients at intended sites of application while reducing inputs to surrounding surface water resources.

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