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Runoff studies were conducted at the University of Minnesota to measure applied nitrogen and phosphorus loss in runoff from creeping bentgrass (*Agrostis stolonifera* L.) turf managed as a golf course fairway. Quantities measured in the edge-of-turf runoff were used to calculate surface water concentrations of a pond receiving runoff from turf. Runoff and surface water concentrations were compared with water quality standards to evaluate potential environmental effects of turf runoff.

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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 1983, the USGA has funded more than 400 projects at a cost of $30 million. 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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# Nutrient Loss in Runoff from Turf: Effect on Surface Water Quality

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## SUMMARY

Excess nutrients in surface waters may result in enhanced algal blooms and plant growth that can lead to eutrophication and a decline in water quality. The application of fertilizer to golf courses may be a source of nutrients to surface waters. Runoff studies were conducted to measure applied nitrogen and phosphorus loss in runoff from creeping bentgrass (*Agrostis stolonifera* L.) turf managed as a golf course fairway. Quantities measured in the edge-of-turf runoff were used to calculate surface water concentrations of a pond receiving runoff from turf. Runoff and surface water concentrations were compared with water quality standards to evaluate potential environmental effects of turf runoff. Key observations of the study were:

- Less than 12% of the applied ammonium nitrogen, nitrate nitrogen, or soluble phosphorus was measured in the runoff.
- Time between hollow tine core cultivation and runoff (2, 11, 15, or 63 days) did not significantly influence the percentage of applied nitrogen and phosphorus transported in the runoff.
- Phosphorus concentrations in runoff were greater than water quality criteria to limit eutrophication.
- Nitrogen concentrations in runoff were greater than levels associated with increased algal growth, while nitrate nitrogen concentrations were below the drinking water standard to prevent blue baby syndrome.
- Phosphorus concentrations in a pond receiving runoff remained above levels associated with increased algal growth and eutrophication of lakes.
- Nitrogen concentrations in a pond receiving runoff were below levels associated with increased algal growth.

A surplus of nutrients in surface waters may result in enhanced algal blooms and plant growth, which, upon their decomposition, leads to reduced dissolve oxygen in the water, eutrophication, and the decline of aquatic ecosystems. The application of fertilizer to agricultural crops, residential landscapes, and golf courses may be a source of nutrients to surface waters (1, 6, 23, 27, 28).

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Fairways comprise approximately one-third of a typcial golf course (31). 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. 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.) (15). Reduced surface runoff has also been observed in turf compared with tilled soils (7). However, golf courses have been shown to contribute to increased nutrient loads in receiving surface waters. King et al. (10) 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.

To control eutrophication, the United States Environmental Protection Agency (USEPA) has established water quality criteria for total phosphorus concentration for lakes and streams (26). In addition, a drinking water standard (maximum contaminant level, MCL) has

A rainfall simulator delivered precipitation to two plots simultaneously a rate similar to storm intensities recorded in Minnesota, USA.

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Runoff gutter and trapezoidal flume for collection of runoff.

been set for nitrate nitrogen ($NO_3$-N) to prevent methemoglobinemia in infants, a potentially lethal condition known as blue baby syndrome (11, 26).

The overall objective of this study was to evaluate the off-site transport and impact of applied nitrogen and phosphorus with runoff from creeping bentgrass turf managed as a golf course fairway. Specific objectives were to: 1) measure runoff volumes and concentrations of soluble phosphorus (sol-P), ammonium nitrogen ($NH_4$-N), and nitrate nitrogen ($NO_3$-N) in edge-of-turf runoff; 2) calculate environmental concentrations anticipated to occur in a surface water (pond) receiving the runoff; and 3) compare concentrations of nitrogen and phosphorus in runoff and a receiving surface water with water quality standards.

## Site Description

The study was conducted at the University of Minnesota Turf Research, Outreach and Education Center, Saint Paul, Minnesota. 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. The site was divided into 6 plots (24.4 m x 6.1 m). Research reported in this study was performed on three of the six plots.

The turf was managed as a fairway with 1.25 cm height of cut (3 times weekly, clippings removed), topdressed with sand (weekly, 1.6 mm depth), and irrigated to prevent drought stress. The quantity of water applied with the maintenance irrigation was not enough to produce surface runoff. Plots were aerated twice during each season with hollow tines (0.95 cm internal diameter x 11.43 cm depth with 5 cm x 5 cm spacing). Cores removed with the hollow tines were allowed to dry, broken into smaller pieces, and worked back into the turf. A back-pack blower and leaf rake removed the turf and thatch from the plot surface.

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 to all plots perpendicular to runoff flow at a rate of 136.5 kg $ha^{-1}$ (24.4 kg N $ha^{-1}$, 1.8 kg P $ha^{-1}$). Immediately following application, the 18-3-18 fertilizer was watered-in (< 1 mm) using the maintenance irrigation system. No additional irrigation or precipitation occurred between completion of fertilizer application and initiation of simulated precipitation (26 ± 13 hours).

A rainfall simulator was constructed based on U.S. patent 5,279,151 (19), which was designed to deliver precipitation to two plots simultaneously at a rate similar to storm intensities recorded in Minnesota, USA. Additional details of the rainfall simulator can be found elsewhere (5).

Runoff collection systems were constructed at the western edge of each plot similar to Cole et al. (4). Stainless-steal flashing guided the runoff from the turf into gutters constructed of polyvinyl chloride (PVC) pipe that lead to a stainless trapezoidal flume equipped with a bubble tube port and two sample collection ports. The runoff collection gutter and trapezoidal flume were supported in sand-filled trenches. Polyester landscape cloth covered the soil under the metal flashing and the banks of the trenches to maintain structural integrity.

Metal flashings were held in place with large nails and paraffin wax provided a water-tight seal between the turf edge and metal flashing. Gutter covers and flume shields prevented dilution of runoff with precipitation. Plots were hydrologically isolated with removable berms, constructed from horizontally-split PVC pipe that were inverted to rest on the cut edges. Observation of water flow during runoff events showed no water movement under the PVC berms.

## Simulated Precipitation

Forty-eight hours prior to initiation of simulated precipitation, each plot was pre-wetted with the maintenance irrigation system beyond soil saturation to ensure uniform water distribution and allow for collection of background samples. Irrigation water samples and resulting background runoff were collected for analysis. The following day the turf was mowed (1.25 cm height, clippings removed), and runoff collection gutters and flumes were cleaned and covered with plastic sheeting to prevent contamination during fertilizer application.


Automated samplers and flow meters recorded volumes, measured flow rates and collected runoff samples.

Prior to application, glass Petri dishes were distributed across the plots to verify fertilizer delivery and determine application rates. Plastic sheeting and Petri dishes were removed following chemical application and rain gauges were distributed throughout each plot to quantify simulated precipitation. Soil moisture was measured in a grid pattern with a soil moisture meter. Simulated precipitation was initiated once wind speeds dropped below 2 m $s^{-1}$ and continued until 90 minutes of runoff had been generated from each plot. Runoff collection was completed 138 ± 4 minutes following initiation of precipitation.

## Runoff Collection and Analysis

An automated flow meter and runoff sampler measured flow rates, recorded runoff volume, and collected runoff samples from each plot.

| Date | | | Precipitation | | |
|---|---|---|---|---|---|
| Core Cultivation[1] | Chemical Application[2] | Precipitation | DAC[3] | Rate | Total Applied |
| | | | | (mm hr$^{-1}$) | (mm) |
| June 21, 2005 | August 22, 2005 | August 23, 2005 | 63 | 34 ± 3 | 59 ±5 |
| September 27, 2005 | September 29, 2005 | September 30, 2005 | 2 | 24 ±4 | 45 ±8 |
| August 4, 2006 | August 14, 2006 | August 15, 2006 | 11 | 35 ±3 | 71 ±8 |
| September 19, 2006 | October 4, 2006 | October 4, 2006 | 15 | 37 ±2 | 75 ±7 |

[1] Hollow tine: 0.95 cm diameter X 11.43 cm depth, 5 X 5 cm spacing.

[2] Plant Nutrient 18-3-18 aookued at kabek rates 22   10 hours prior to precipitation.

[3] DAC = days after cultivation (days between core cultivation and initiationn of simulated precipitation.

**Table 1.** Timeline and precipitation data.

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 fertilizer granules served as blank and positive control samples. Water samples were analyzed for soluble phosphorus (sol-P), ammonium nitrogen ($NH_4$-N), and nitrate nitrogen ($NO_3$-N) following standard methodologies (2, 17, 22).

## Calculation of Surface Water Concentrations

Nutrient loads (mg m$^{-2}$) from edge-of-plot runoff were calculated from recorded runoff volumes (L m$^{-2}$) and measured concentrations (mg L$^{-1}$) of sol-P, $NH_4$-N, and $NO_3$-N in the runoff. Concentrations of nitrogen and phosphorus in a body of water receiving the runoff was determined according to the scenario utilized in the Exposure Analysis Modeling System (EXAMS) model where runoff from a 10-ha (100,000 m$^2$) area drains into a pond with 1-ha (10,000 m$^2$) surface area and 2-m depth (www.epa.gov/oppefed1/models/water/). This was accomplished by calculating the average nutrient loads for all plots from the four runoff events then extrapolating to determine the load from a 10-ha area. The total mass for each chemical of interest was then divided by the total volume of the theoretical pond to give the estimated environmental concentration, which can be compared to water quality criteria and drinking water standards.

Completely randomized analysis of variance (ANOVA) was performed comparing the percent of applied precipitation resulting as runoff and the percent of applied chemicals transported in runoff for all runoff events (25).

## Results

### *Precipitation Depth and Runoff Volumes*

Rain gauges distributed throughout the plots measured rainfall rates of 24 ± 4 mm h$^{-1}$ to 37 ± 2 mm h$^{-1}$ for a total of 45 ± 8 mm to 75 ± 7 mm of precipitation (Table 1). Variations in generated rainfall rates for the simulation events were most likely the result of changes in pressure at the water source during the time of simulated precipitation. Measured coefficient of uniformity for the rainfall simulator was 82 to 84%.

Precipitation and collection of runoff was initiated 2, 11, 15, and 63 days following aerification (Table 1). Volumetric soil moistures measured less than 2 hours prior to initiation of precipitation and 48 hours post-saturation were 45 ± 4

% with post-simulation (< 3 hours) moisture measurements of 68 ± 3%. Runoff was first observed 22 ± 7 minutes following the initiation of precipitation (Figure 1A). Steady-state runoff rates were observed for 56 ± 9 minutes beginning approximately 60 minutes after the initiation of precipitation with average flow rates of 22 ± 6 L min$^{-1}$ and maximum flow rates of 43 ± 9 L min$^{-1}$. Runoff collected from turf plots 2, 11, 15, and 63 days following hollow-tine aeration represented 28 ± 2%, 33 ± 8%, 35 ± 1%, and 36 ± 11% of the water applied as precipitation, respectively (Figure 1B).

Although the mean percentage of applied precipitation resulting as runoff appeared to increase with a greater time differential between aeration and runoff, the trend was not statistically significant. This suggests the turf recovery rate and filling of holes with soil and plant biomass following hollow tine core cultivation did not significantly impact overland flow volumes. Shuman (24) observed 37 to 44% of applied water as runoff from fairways of 'Tifway' bermudagrass that received 50 mm of simulated precipitation two days following irrigation to field capacity. This is in range of our observations, though core cultivation was not reported in their study.

We observed a larger percentage of runoff and increased time to runoff relative to the study of Kauffman and Watschke (9) where 25 minutes of simulated rainfall (152 mm h$^{-1}$) applied to creeping bentgrass plots 2, 9, and 16 days following hollow-tine core cultivation resulted in 3.7 to 10% of the applied precipitation as runoff. Similar to our study, the mean volumes for the runoff events were not statistically different with increased time differential between aeration and runoff. We speculate the increased runoff observed in our experiment is the result of greater pre-simulation soil moistures as the plot size and precipitation quantities were relatively similar.

A direct relationship between runoff volume and soil moisture at the time of the precipitation event has been reported (24). The delay in time to runoff observed in our study compared to the study of Kauffman and Watschke (9) is most likely the result of a more gradual plot slope (4% rather than 9-11%), lesser precipitation rates (24-37 mm h$^{-1}$ rather than 152 mm h$^{-1}$), and removal of deeper and more closely spaced cores (depth x spacing x diameter: 11.43 cm x 5 cm x 0.95 cm rather than 3.8 cm x 6.4 cm x 1.6 cm).

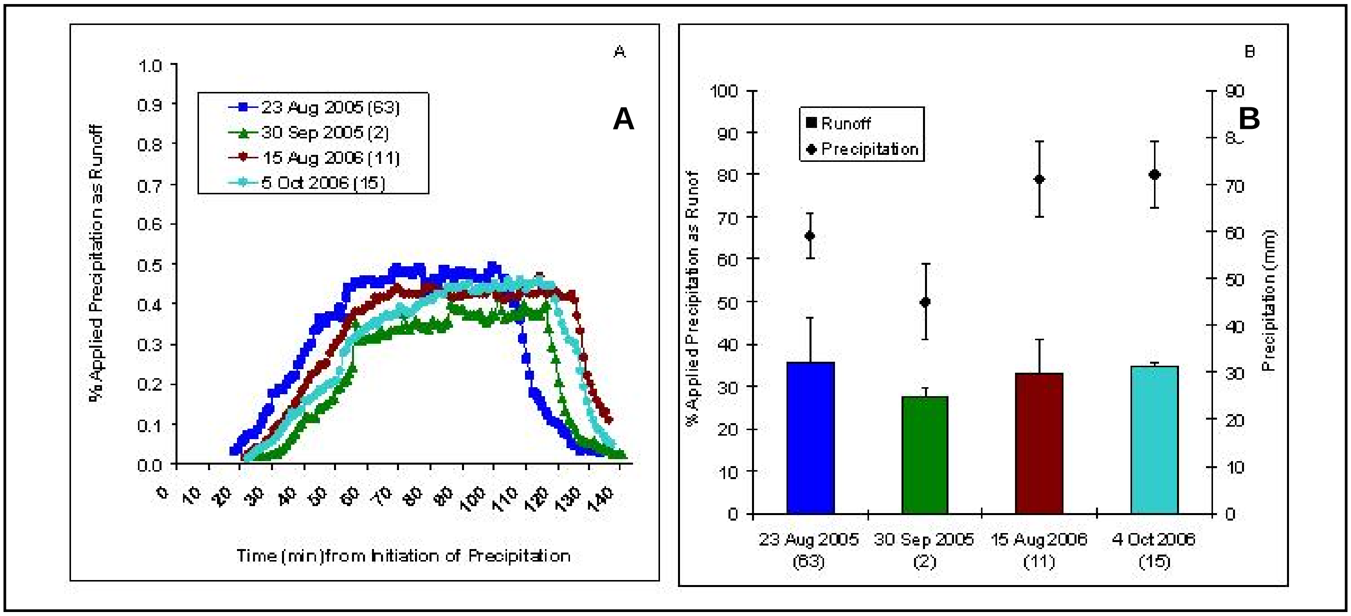

**Figure 1.** (A) Runoff hydrographs from creeping bentgrass turf managed as a golf course fairway. (B) Precipitation and percent of precipitation resulting as runoff. Numbers displayed parenthetically represent days between hollow tine core cultivation and runoff.

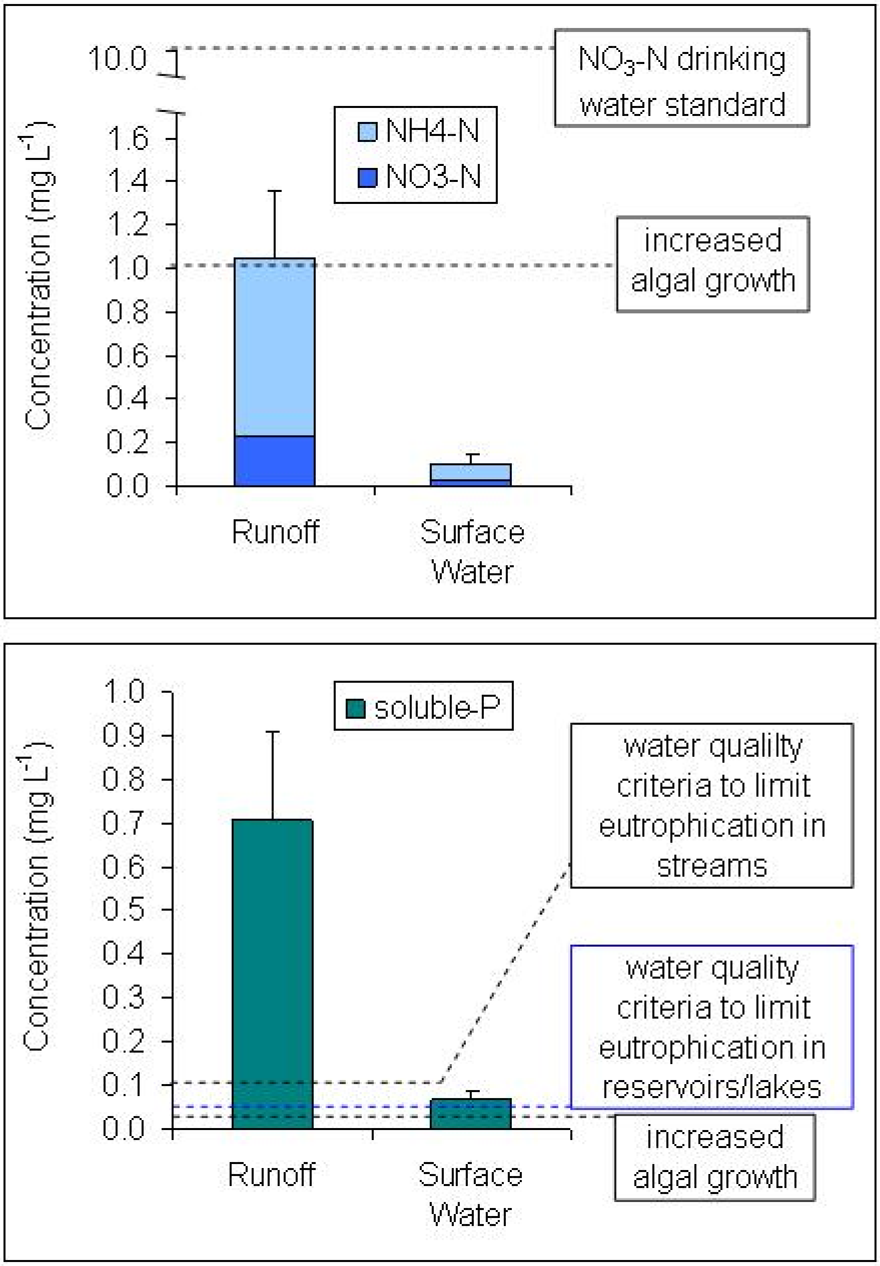

**Figure 2.** A comparison of water quality standards with nutrient concentrations in edge-of-turf runoff and a surface water (pond) receiving runoff from turf.

### *Nitrogen and Phosphorus Concentrations in Runoff*

Analysis of the source water applied as maintenance irrigation and simulated precipitation contained negligible levels of $NH_4$-N, $NO_3$-N, and sol-P (0.001 to 0.005 mg $L^{-1}$). Average concentrations measured in the runoff for the four evaluated events were as follows: $NH_4$-N = 0.82 ± 0.26 mg $L^{-1}$, $NO_3$-N = 0.23 ± 0.07 mg $L^{-1,}$ and sol-P = 0.71 ± 0.20 mg $L^{-1}$ (Figure 2). Our edge-of-plot runoff contained phosphorus concentrations that were 7 and 14 times greater than USEPA water quality criteria to limit eutrophication within a stream (total phosphorus 0.1 mg $L^{-1}$) or lake/reservoir (total phosphorus 0.05 mg $L^{-1}$) (21, 26). Concentrations of $NO_3$-N were below the drinking water standard (10 mg $L^{-1}$ $NO_3$-N) (11, 21), which is consistent with the findings of other turf runoff studies (7, 14, 16).

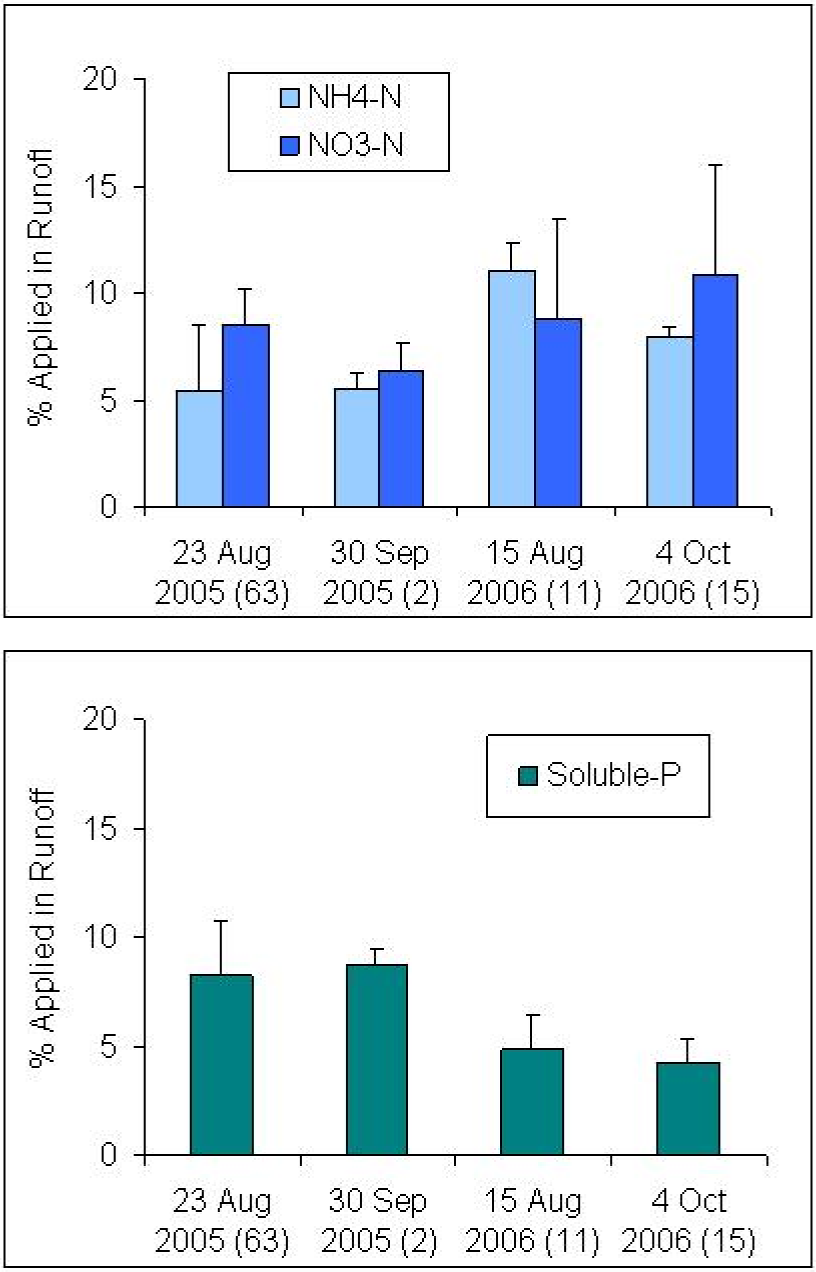

**Figure 3.** Percent of applied ammonium nitrogen ($NH_4$-N), nitrate nitrogen ($NO_3$-N) and soluble phosphorus (Soluble-P) measured in runoff from creeping bentgrass turf managed as a golf course fairway.

The mean percentages of applied $NH_4$-N, $NO_3$-N, and sol-P transported in runoff with each event are presented in Figure 3. Statistical analysis revealed the percentage of applied $NH_4$-N or $NO_3$-N in runoff was similar regardless of the time differential between hollow tine core cultivation and runoff (2, 11, 15, or 63 days) or the date the runoff was collection (2005 or 2006, mid-August to early October). The average percentage of applied chemical transported in runoff for the four runoff events was 7.5 ± 2.7 % for $NH_4$-N and 8.6 ± 1.8 % for $NO_3$-N. For sol-P, the mean percentage of applied transported in runoff was 8.5 ± 0.3 % in 2005 and 4.6 ± 0.5 % in 2006.

Closer observation of the individual runoff events revealed this difference was not the result of the time differential between hollow-tine core cultivation or the month of runoff collection as there was no statistical difference between runoff events occurring within the same year (Figure 3).

For all runoff events, the turf was actively growing. Additional evaluation of thatch, turf, and soil samples will be required to fully explain the divergence observed in sol-P in runoff from 2005 and 2006.

Overall, less than 12% of the applied $NH_4$-N, $NO_3$-N and sol-P were measured in the runoff from our turf plots. This is in range with observations reported by other researchers. Linde and Watschke (14) measured 11% of applied phosphorus and 2% of applied nitrogen in runoff from creeping bentgrass and perennial ryegrass 8 hours after fertilization. Shuman (24) observed 10% of applied phosphorus and less than one percent of applied $NO_3$-N was found in the first runoff event occurring 4 hours after application to simulated golf course fairways of bermudagrass. Cole et al. (4) reported less than one to 10% of applied nutrients were transported in runoff from bermudagrass turf depending on the amount of precipitation, soil moisture, and management.

### *Concentrations in a Pond Receiving Runoff*

Calculation of environmental concentrations in the receiving surface water resulted in $0.08 \pm 0.03$ mg $L^{-1}$ $NH_4$-N, $0.03 \pm 0.01$ mg $L^{-1}$ $NO_3$-N, and $0.07 \pm 0.02$ mg $L^{-1}$ sol-P. After dilution of runoff in the pond, phosphorus concentrations remained above levels associated with increased algal growth (0.025 mg $L^{-1}$) and the USEPA water quality criteria to limit eutrophication in lakes and reservoirs (0.05 mg $L^{-1}$) (21, 30) (Figure 2).

Nitrogen concentrations ($NH_4$-N + $NO_3$-N) were an order of magnitude below levels associated with increased algal growth (1 mg $L^{-1}$). Nitrate nitrogen concentrations were 400 times below the drinking water standard (10 mg $L^{-1}$) (11, 26) (Figure 2). This corresponds to the review of Cohen et al. (3) where drinking water standards for $NO_3$-N were not exceeded in any of the surface water samples reported in 17 studies covering 36 golf courses.

As efforts to ban or restrict the use of chemicals on residential turf are proposed and enforced (8, 13, 20, 29), quantitative information on the off-site transport of chemicals with runoff will be valuable in providing scientifically-based data for making informed decisions. Runoff and chemical data collected from this study can be utilized to evaluate predictive runoff transport models and to assess non-point source pollution potential of nutrients transported in runoff from turf. Greater knowledge of chemical fate and associated risk will allow for modified or restricted use where a hazard potential has been demonstrated while maintaining the use of these products as tools for managing turf where a plausible risk is unproven.

## Acknowledgements

The described research was conducted as part of a multi-state collaborative effort to obtain standardized regional data on the fate and transport of turf protection products. Runoff and fertilizer data are reported here. Pesticide data and the use of management practices to reduce chemical transport with runoff from turf will be reported in future *TERO* and journal publications or are published elsewhere (12, 19).

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