

Turfgrass Management Influence on Water Quality

Part 2: Nutrients

A Healthy Ecosystem

Nutrients and pesticides found in water supplies can cause problems for both humans who rely on clean water for consumption, irrigation and recreation, and organisms that must have clean water for survival.



Editor's Note: This is the second of a three part series on the current status of water quality research as it relates to turfgrass management. Part 1, Pesticides, was published in the Winter 2004 issue of CUTT.

Concern about sources of agricultural pollution has raised questions about the contribution of turfgrass to water contamination and has motivated research on the role of pesticides and nutrients on contamination of water supplies. Turfgrass, while not the largest acreage crop, is in many cases the most intensively managed ecosystem. However, turfgrass management does not necessarily imply environmental degradation; in fact turf provides many benefits. The functional, recreational and aesthetic benefits provided to humans are unmatched by other crops.

Turf provides sediment reduction, runoff control, flood control, reduction in point- and non-point source pollution, water filtration, heat dissipation, and oxygen production. In many cases turfgrass has been used to remediate harmful chemicals leaving a site. Daniels and Gilliam found runoff transported from agricultural fields and flowing through a grass filter underwent significant sediment and chemical load reductions. In fact, the grass filter was more effective at reducing chemicals and sediments than the use of both a grass and a riparian filter.

Golf courses have been shown to be effective filters of surface water, especially for nutrients such as ammonium ($\text{NH}_4^+\text{-N}$) and, in some cases, nitrate ($\text{NO}_3^-\text{-N}$). To be an effective filter, grass must produce a dense canopy, and deep, fibrous roots, which are capable of removing water from the soil at great depths. A dense canopy will slow and filter chemicals from runoff. Increased plant shoot density will reduce runoff and hence the chemical load leaving a site by creating a more tortuous pathway and increasing soil infiltration of water.

In any case, nutrients and pesticides found in water supplies can cause problems for both humans who rely on clean water for consumption, irrigation and recreation, and organisms that must have clean water for survival. The Environmental Protection Agency (EPA) has established maximum contaminant levels (MCL) for drinking water, above which human consumption is unsafe. The effect of these MCLs on aquatic organisms is generally much greater, suggesting that the use of aquatic toxicities may be a better indicator of water contamination. An in-depth review of the literature reveals a lack of work regarding the specific effect of pesticide use, differing nutrient sources and management practices on drainage water quality from turfgrass.

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The form of P loss in runoff is generally site specific, with densely vegetated sites contributing more soluble P, and sites prone to erosive losses contributing more insoluble P. Efforts to reduce erosion can reduce both the dissolved soluble P and the particulate insoluble P, however reducing soluble P losses alone is much more difficult.

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Phosphorus

As with pesticides, P transport to water supplies was once thought to be of minor importance, due to the ability of the soil to tightly bind, or precipitate P out of solution. However, P has the potential to cause eutrophication in surface water at levels as low as 0.035 mg L⁻¹ and 0.05 mg L⁻¹, making detection below the EPA MCL of 2 mg L⁻¹ still a concern.

Findings vary on where the majority of P is lost. Quinton et al., saw that P, being relatively insoluble and easily bound, was not at risk to be lost in the soluble form, but was more at risk to be lost with sediment, through erosive processes. Quinton et al. and Cox and Hendricks both observed that as sediment loss increased, so to did P loss, due to the P being sorped to soil particles.

Conversely, Shuman et al. state that most of the P lost from grassed pastures is lost in the soluble form presumably due to negligible sediment losses. Gross et al. and Krenitsky et al. also found significant sediment reduction from turf. Bush and Austin found that 90% of the P loss in runoff from a perennial pasture was soluble P. The form of P loss in runoff is generally site specific, with densely vegetated sites contributing more soluble P, and sites prone to erosive losses contributing more insoluble P. Efforts to reduce erosion can reduce both the dissolved soluble P and the particulate insoluble P, however reducing soluble P losses alone is much more difficult.

In many cases, fertilization on a crops N needs results in over-application of P, especially with the use of manures. Sharpley and Smith saw an 800% increase in soil P content following manure application. P levels in the first runoff after fertilization can be orders of magnitude higher than following runoff events. Pote et al. found that the concentrations of both N and P in runoff increased following application of swine manure.

Manures generally have the potential to contribute more P to both ground and surface water. Ebeling et al found that both the concentration and total P load was the highest in runoff from plots treated with high P diet dairy manure. Sharpley and Moyer measured very high P levels in leachate, 75 mg L⁻¹, from dairy and swine manure.

Phosphorus Transport

Phosphorus transport follows some complicated processes. It is found in both soluble and insoluble forms, which can be moved with water, or sediment. It can be sorbed out of solution by metal cations such as iron or aluminum, effectively binding the P to cation exchange sites removed from solution by mineral precipitation, or taken up by the plant. In soils with macropores or preferential flow component P may bypass the soil matrix, and be transported directly to ground water. Saturation of the soils cation exchange sites with the metal PO₄³⁻ ions can result in subsequent transport of P offsite.

Once these CEC sites are saturated, P removal and unsaturation can take a long time and is dependent heavily on the solubilization rate, plant needs and uptake rate. Robertson and Wilhelm et al. explored this in greater detail and found that once these CEC sites are saturated, PO₄³⁻ movement is retarded, but only attenuated by 25%, and ultimately mobile. At steady state PO₄³⁻ concentrations, all exchange sites are presumed to be saturated, thus further attenuation of P results from mineral precipitation.

Robertson and Harmon found that once in the ground water zone PO₄³⁻ attenuation slows dramatically, and as a result, most is ultimately mobile.

Increased levels of aluminum and aluminum chloride had a significant impact on P runoff reduction by reducing the pH and hence the solubility. In this study swine manure was treated with Al to reduce the P solubility and the potential to runoff.



Observed P concentrations in runoff fell from 5.75 mg L⁻¹ for swine manure with no Al addition to <1 mg L⁻¹ for swine manure with 430 mg Al L⁻¹ added to the manure.

The Al, Ca and Fe oxides in the soil reduce P solubility by lowering pH and causing P to form metal ions and be bound at exchange sites. Torrent and Delgado also explored the role of Al and Fe oxides in P sorption process, stating that these are the most active P fixing ions in the soil. As such, soils with high metal oxide levels are better able to remove P from the soil solution, and thus reduce its mobility in runoff and leachate. However, soils high in macropores have been shown by Sinaj et al. to allow increased P losses. The macropores reduce contact of the Al and Fe oxides with the soil, allowing P and the metal oxides to leach from the profile.

Outflow from the lysimeters in this study was observed very quickly, < 5 min to travel 70 cm and contained P transported through the preferential flow paths. Turner and Haygarth found that erosive processes in the macropores can contribute significant P to vadose zone water by physical detachment and transport of bound P. The role of Ca precipitation and pH was explored by Harris et al., who found that despite high pH and abundant calcium, there was essentially no Ca-P mineral formation, indicating a high P availability was still present in the matrix. At higher pH P leaching may be reduced by precipitation with Ca. Organic carbon can increase P losses by coating binding and precipitation sites in the soil.

Shuman et al. observed PO₄³⁻ concentrations of 2.7 mg L⁻¹ during the first runoff event following fertilizer application, but levels declined rapidly thereafter. Maximum leachate concentrations were even higher, greater than 3 mg L⁻¹. The concentrations increased in the fall because of reduced plant uptake. Young and Ross observed mean porewater PO₄³⁻ concentrations as high as 7 mg L⁻¹ in from soils with high levels of extractable P. Low PO₄³⁻ concentrations (0.046 mg L⁻¹) were detected in soils with low levels of extractable P. Turner and Haygarth saw concentrations of about 0.5 mg L⁻¹ in drainage water from lysimeters, which was highest in the spring, presumably due to solubilization in saturated soils.

Bush and Austin measured TP concentrations in runoff and leachate of > 90 mg L⁻¹ in the first irrigation event following fertilizer application. Concentrations decreased to < 6 mg

L⁻¹ in runoff and < 4 mg L⁻¹ in leachate following the second irrigation event. Subsequent events resulted in an exponential decline in TP levels. Quinton et al. saw concentrations as high as 25 mg L⁻¹ in runoff due to erosive losses. Gallimore et al. recorded dissolved P concentrations in runoff from manure treated plots as high as 17 mg L⁻¹. Cole et al. measured PO₄³⁻ concentrations of 9.57 mg L⁻¹ in runoff.

Runoff and leachate from fertilized areas is not the only source of P in water. A study implemented by the United States Geological Survey (USGS) and compiled by Waschbusch et al. found that forested areas, roofs, and streets all contributed significant amounts of P in water, higher in many cases than losses from fertilized areas.

Nitrogen

Nitrogen found in water supplies can cause eutrophication, algal blooms and impaired water quality at levels well below those considered safe for human consumption. However, this is only when P is not limiting which is usually not the case in the temperate Northeast. Walker and Branham state that NO₃⁻ concentrations as low as 1 mg L⁻¹ can have negative implications for water. Casey and Kline found that levels above 0.4 mg L⁻¹ cause problems for marine organisms. Mallin and Wheeler found that even lower levels of 0.1 mg L⁻¹ NO₃⁻ cause problems in water. While P is the primary limiting agent in freshwater, N can be the limiting agent for eutrophication in many estuarine and marine systems. Nitrate at levels above 2 mg L⁻¹ can cause hypoxia in water, and NO₃⁻ concentrations >0.05 mg L⁻¹ can cause decline in costal fish habitat. Clearly there is a threat to water from over fertilization.

In a turfgrass system, establishment is the most dangerous from an N loss standpoint, as fertilization rates generally do not change significantly. Lower plant N needs, coupled with undeveloped root systems and lack of soil cover, leads to greater leaching and runoff losses. This presents a good argument for sodding potentially dangerous sites. Sod has been shown to work better than essentially any other material at reducing sediment and runoff losses.

In a study by Snyder and Cisar NO₃⁻ levels in leachate from a sand green were 20-200 mg L⁻¹ for three months following establishment. Leachate losses from fairways were an order of magnitude lower, likely attributable lower sand and higher clay content of the soil. Following

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establishment, concentrations in leachate from both the fairway and greens were generally below 10 mg L⁻¹. Greater than 100% of the applied N was recovered from the lysimeters indicating that excess N can stimulate mineralization or microbial release of NO₃⁻ from the soil. In a study by Rosenthal and Hipp, extremely high NO₃⁻ levels of > 300 mg L⁻¹ were measured in runoff from turfgrass. Owens et al. found that the majority of N leaving a grass pasture was associated with water leaching past the root zone.

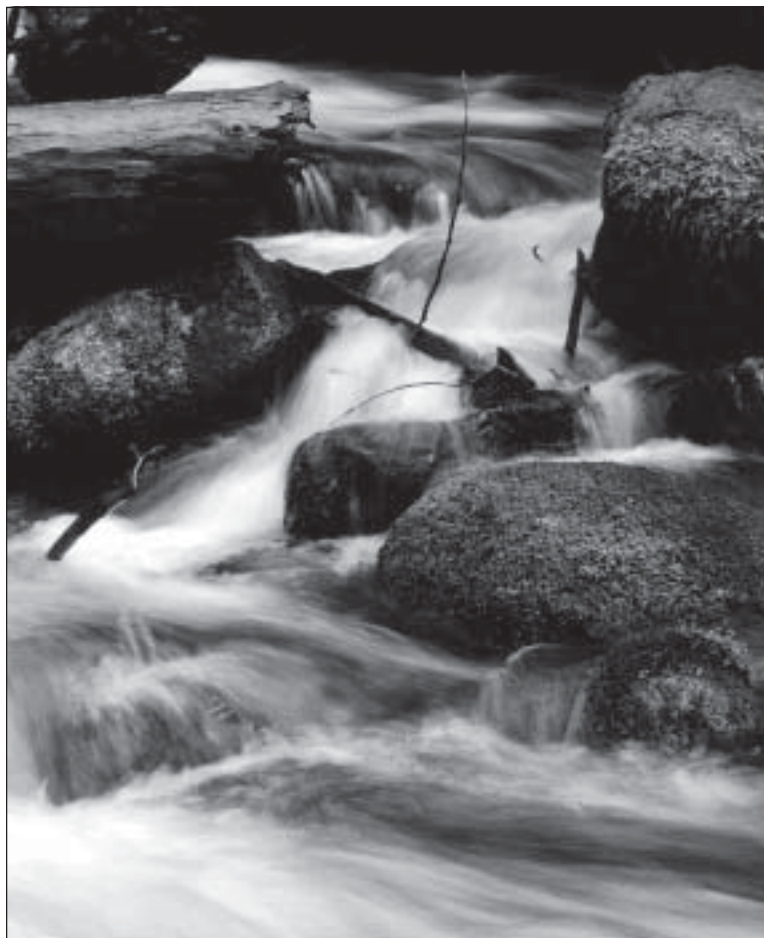
In a study completed by Quiroga-Garza et al. that factored in day length, NO₃⁻ levels in leachate were extremely high, 100-190 mg L⁻¹, accounting for 9% of applied N. This was because of reduced turfgrass vigor and growth from shorter photoperiod. Brown et al. saw levels of NO₃⁻ in leachate up to 100 times higher from highly soluble NH₄NO₃, than from less soluble urea formaldehyde. This finding was verified in another study by Owens et al. who found that ground water below grass pastures fertilized with NH₄NO₃ had significantly higher NO₃⁻ concentrations than pastures fertilized with slow release N.

Baird et al. speculated that sulfur-coated urea contributed lower surface water N levels due to reduced solubility of the prills, and hence a slower, more controlled release. Rate can also play a role in N loss; high rates applied to sandy soils during times of excessive rainfall or irrigation are much more prone to leachate losses. Application timing was associated with NO₃⁻ peaks observed in leachate by Shuman et al. The peaks were higher following fall fertilization than for summer due to reduced turf growth and uptake of NO₃⁻. Lui et al. found that leaching potential fluctuated seasonally and was strongly related to precipitation, relative plant growth rates, fertilization source and timing. Quiroga-Garza et al. observed that late season N applications resulted in significantly higher N leaching losses. Conversely, Miltner et al. state that N fertilization of turf in late fall does not pose a threat to groundwater.

Nitrogen Loss

With established turfgrass, clippings are generally the largest sink of N, accounting for 25-60% of applied N. Miltner et al. recovered well over 50% of applied N in clipping, verdure, and thatch. The N bound in turf tissue does not generally represent a threat to water quality, as it is utilized by the plant, and prevented from entering water supplies.

Most of the N lost is via leachate. While runoff can contain high concentrations of nutrients, fluxes are much lower from runoff than from leachate. Owens et al. saw average NO₃⁻ levels in runoff of only 2 mg L⁻¹ in the 10-year study. The low average NO₃⁻ concentrations may have been due in part to dilution, as the surface runoff depths were high, > 100 mm, for the growing season in



some cases. They saw > 75% of the NO_3^- lost in leachate. Concentrations of 20 mg L^{-1} were recorded in leachate. Miltner et al. measured a total of only 0.18% of N_{15} labeled nitrogen in the leachate, and very low levels throughout the study, $<1 \text{ mg L}^{-1}$. However, increased NO_3^- concentrations were detected early in the study, which was attributed to mineralization of N due to soil disturbance.

Due to the mobility of NO_3^- in the soil solution, and its solubility, ground and surface water are potentially at great risk for contamination. NO_3^- can move rapidly through sandier soils which allows infiltration to proceed rapidly. Excessive irrigation following fertilization has been shown to mobilize NO_3^- leaching. Starrett et al. found up to 30 times more NO_3^- leached under heavy irrigation, and 95% occurred within 10 hours of irrigation. In total, 10% of the applied N was recovered in leachate from the soil within 10 hours. Lui et al. saw up to 30% of applied N leached, mainly in the winter when plant up take is minimal. Levels were as high as 12 mg L^{-1} in the winter. Petrovic came to the conclusion that leaching losses are high when temperatures are cool, precipitation is high, and plant up take is minimal.

While turfgrass generally has a high affinity and need for N, excess will move from the site. Soils planted with turfgrass will have an increase in organic matter due to root turnover, dieback and thatch deposition. The organic matter has the ability to hold large quantities of N, but will eventually reach equilibrium. Once reached, excess N will be lost, generally to leaching. Quiroga-Garza et al. also found that established stands will utilize and retain more N in the thatch.

Rooting depth was found by Bowman et al. to be a major factor affecting NO_3^- leaching. They found that deeper rooted, i.e., more mature, turf was able to reduce the NO_3^- concentrations in leachate by 100% over shallow rooted turf. Once the N has moved past the root zone, little attenuation will take place, and it can be assumed that it will reach the water table at the

same concentration. Lui et al found that NO_3^- will not move back up into the root zone once it has leached past. In addition they saw the highest losses of N in the winter, when the turfgrass plant was not actively growing, pulling the N out of the soil.

Turf to the Rescue

Despite this, turf has a great potential to remove nutrients and pesticides from water. Mallin and Wheeler note numerous cases when water flowing through golf courses was cleaner at the outflow than it was at the inflow. They state the P is much more difficult to remove from the water than was NH_4^+ or NO_3^- . Nutrient levels detected at the course outflow were always below MCLs, and in most cases below levels thought to cause problems for aquatic organisms. They reason that the reductions were due to the thick vegetated buffers of stream channels on the course.

As with P, water supplies receive significant input of N from non-fertilized sources. Owen et al. recorded concentrations of $>1.0 \text{ mg L}^{-1}$ NO_3^- -N, and $>2.0 \text{ mg L}^{-1}$ of mineral-N in precipitation, accounting for about 10% of total N input. In nitrogen loading studies conducted on an estuary, Valeila et al. estimate that wastewater input from septic fields accounts for 48% of N input, atmospheric deposition 30% on N input, and fertilization only 15% of N input to water bodies. Clausen et al. recovered about 1% of total N additions via rainfall.

Casey and Kline measured NO_3^- concentrations of 7.7 mg L^{-1} in greens runoff. Increasing N fertilization on sand-based greens can result in impaired water quality. Thus, greens pose a threat to ground water supplies due to the sandy soil, intensive management and intensive input.

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