Research *You Can Use*

Nutrient Fate and Transport

Reviewing USGA–funded research.

BY JEFF NUS AND MICHAEL KENNA

What happens to nutrients after fertilizers are applied? How much are these nutrients transported to groundwater or surface waters, and what are the ecological effects? What can be done to minimize this risk?

During the past decade, the USGA Turfgrass and Environment Research Program continued answering these questions. The focus of this effort was to determine adverse ecological effects when nutrients are transported from the site of application. The two nutrients receiving attention were nitrogen (N) and phosphorus (P), and much was learned about how to effectively limit the risk of these nutrients finding their way to surface and groundwater.

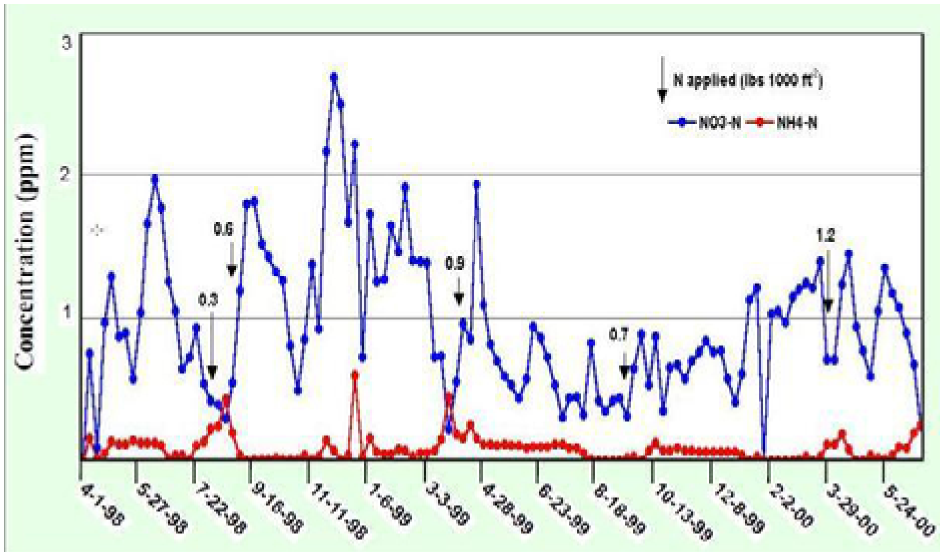


Figure 1. Leachate nitrogen concentrations from a golf green at Coeur d'Alene, Idaho, 1998-2000 (11). Arrows indicate timing and amounts of nitrogen applications (lbs. of N per 1000 sq. ft.). Although nitrogen leaching increases 7 to 21 days following a fertilizer application on sand-based putting green, the amount of N leached poses little potential for groundwater contamination.

NITROGEN

Nitrogen-containing fertilizers are used to stimulate and maintain turf growth, although applied nitrogen can be lost via ammonification, leaching past the rootzone, runoff in surface water, and use by soil microorganisms. In general, nitrogen runoff and leaching losses from turfgrass are minimal in studies, including creeping bentgrass (8, 11, 15), Kentucky bluegrass (7), zoysiagrass (19), and bermudagrass (2, 3, 4, 16).

Research at Michigan State University on Kentucky bluegrass demonstrated that a 10-year-old stand required less nitrogen to maintain turf (7). If annual rates of 5 lbs. N per 1,000 sq. ft. are continued for mature Kentucky bluegrass turf, then leachate will contain unacceptable amounts of nitrate-nitrogen. However, it is important to note that less than 1% of groundwater samples collected for 20 years from 44 golf courses exceeded nitrate-nitrogen maximum contaminant levels, as set by the U.S. Environmental Protection Agency (1).

On newly constructed sand-based putting greens, research at Auburn University showed that nitrate leaching was greater in the first four months after construction but decreased substantially as the green matured and nitrogen fertilization was reduced to maintenance levels (8). During the first year after construction, nitrogen is sequestered in the surface organic layer of greens. Subsequently, an equilibrium is established between sequestering nitrogen and mineralization of nitrogen by microbes (16). Although research by Washington State University demonstrates that nitrogen leaching increases 7 to 21 days following fertilizer application on mature, sand-based greens (Figure 1), the amount of nitrogen leached poses little potential for groundwater contamination when healthy turfgrass is maintained (11).

Nitrogen runoff from fairways is a greater threat to water quality than drain outlets from greens and tees because of the increased acreage, greater slopes, and higher application rates for fairways (16). The USGA supported water-quality monitoring studies of fairway turfgrass, as well as golf course watershed studies, to provide a larger-scale perspective of potential nutrient loss (4, 12, 13, 19, 20).

At Oklahoma State University, normal rainfall caused 0.5% of the nitrogen applied to run off a bermudagrass golf course fairway with a 5% slope (Figure 2). During a season of near-record rainfall, this same fairway lost 1.3% of the nitrogen applied as fertilizer (3, 4). Nitrate-nitrogen concentration in runoff from a northern Minnesota golf course site during storm flow events was 3.3% of the applied nitrogen (12). Researchers noted, though, that nitrate-nitrogen concentrations and load transported through the subsurface drainage water

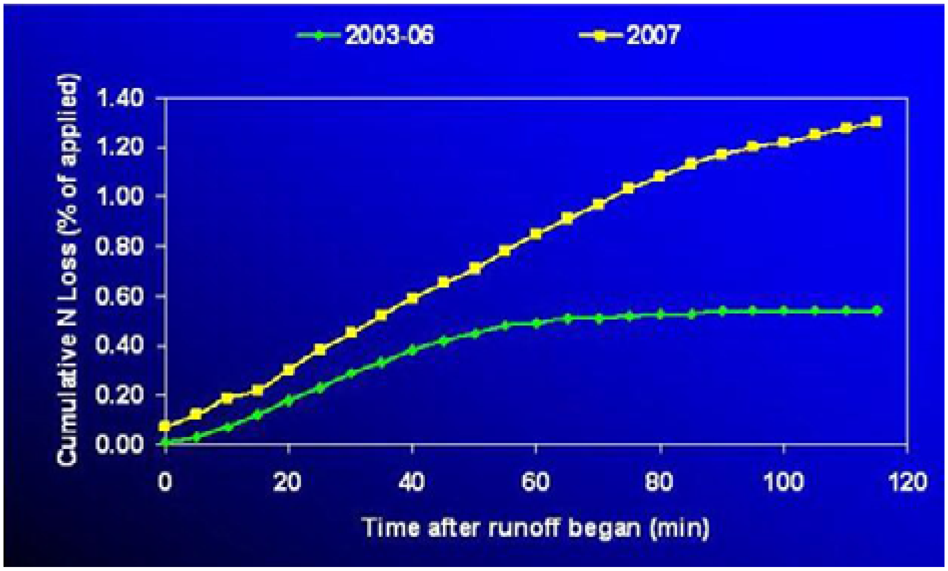


Figure 2. The average amount of nitrogen (N) lost in natural rainfall from a bermudagrass fairway study site at Oklahoma State University in 2003 through 2006 (green line) and in the abnormally high rainfall of 2007 (yellow line). Runoff losses are measured as percentage of N applied. Normal rainfall caused 0.5% of the N applied to run off a bermudagrass golf course fairway with a 5% slope. During a season of near-record rainfall, this same fairway lost 1.3% of the N applied as fertilizer (3).

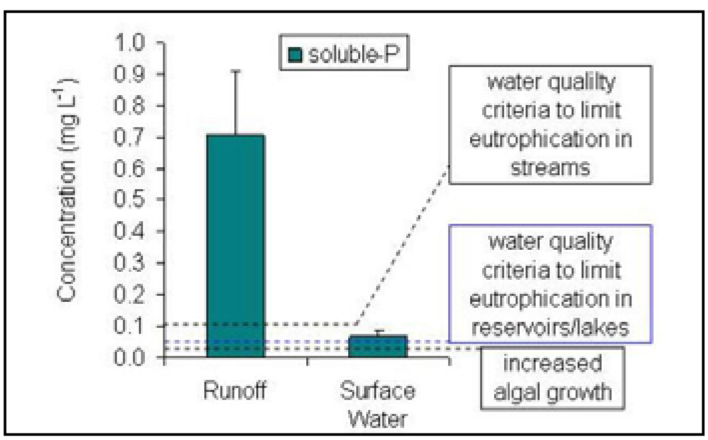
were approximately one-tenth the concentration and load typically reported for tile drainage from row crop agriculture (12).

PHOSPHORUS

The results of water quality monitoring studies indicate minimal degradation of ground and surface water from nitrogen; however, data regarding phosphorus is more troublesome. Phosphorus concentrations exceeded acceptable levels in 86% of ground and surface water samples collected from 44 golf course water quality monitoring studies spanning 20 years (1). Part of the reason for the large percentage of water samples exceeding the criteria for phosphorous is the very low concentration of total phosphorous allowed by the U.S. Environmental Protection Agency.

Research at the University of Minnesota (15) indicated that phosphorus concentrations in runoff from fertilized turfgrass remained above levels associated with increased algal growth and eutrophication of lakes (Figure 3). Research at the University of Maryland indicated that greater phosphorus runoff from large-size plots was attributed to mass transport of triple superphosphate granules in large streams of runoff that developed within these plots during a rainstorm event (5).

Oklahoma State University scientists estimated that under normal conditions, a bermudagrass golf course fairway on a 5% slope was likely to lose around 2% of the phosphorous applied as fertilizer (Figure 4). However, during a season of near-record rainfall, this same fairway would lose about 7.7% of the phosphorous applied as fertilizer (4). In addition, a U.S. Department of Agriculture (USDA) water quality monitoring study in Austin, Texas, reported that dissolved reactive phosphorus (DRP) concentrations in the subsurface drainage water exiting a golf course were greater than concentrations measured in tile drains from



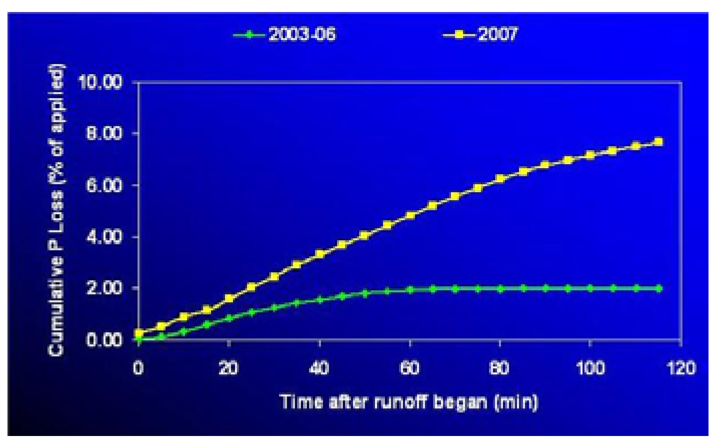


Figure 3 (above left). University of Minnesota research indicated that phosphorus concentrations in a pond receiving runoff from fertilized turfgrass were above levels associated with increased algal growth and eutrophication of lakes. Water quality standards are compared with nutrient concentrations in edge-of-turf runoff and surface water (pond) receiving runoff from turf (15). Figure 4 (above right). The average amount of phosphorous (P) lost in natural rainfall from a bermudagrass fairway study site at Oklahoma State University in 2003 through 2006 (green line) and in the abnormally high rainfall of 2007 (yellow lines). Runoff losses are measured as percentage of P applied. Normal rainfall caused 2.0% of the P applied to run off a bermudagrass golf course fairway with a 5% slope. During a season of near-record rainfall, this same fairway lost 7.7% of the P applied as fertilizer (3).

Recent research studies have utilized much larger study plots or entire watersheds to characterize nutrient losses from golf courses.

Runoff studies at several universities have shown that nutrient runoff from applied fertilizers can be reduced by not applying fertilizers when soils are saturated.

agriculture (13). The reported concentrations could pose a potential threat of eutrophication to a surface water system.

FACTORS AFFECTING NUTRIENT LOSS

The amount of nutrient loss is closely tied to the level of nutrients applied for both nitrogen and phosphorus. Sites receiving higher application rates of nitrogen and phosphorus lost more of these nutrients as runoff compared to sites receiving lower application rates (13). In addition, both nitrogen leaching and runoff follow a strong seasonal pattern where nitrate concentrations are highest during winter months when turf is dormant, precipitation is more plentiful, and microbial activity is reduced (7, 13). For this reason, fertilizers should not be applied to turf too early or late in the growing season.

Water quality monitoring conducted by Kansas State University before, during, and after construction of Colbert Hills Golf Course indicated that water quality was most adversely affected during the construction phase, although heavy storm events increased runoff, erosion, and nutrient transport at any stage (19, 20). During construction, nutrients found in streams and ponds were from soil erosion (19).

The amount of rainfall or irrigation plays a key role in determining nutrient runoff and leaching. In a study conducted by Oklahoma State University on bermudagrass fairway turf (4), a near-perfect relationship was established between the amount of natural rainfall runoff that occurred and the amount of nutrient lost (Figure 5). Research completed by the USDA in Texas indicated that the timing of nitrate-nitrogen and DRP through subsurface drainage from golf course turf is dependent on climatic factors (temperature and precipitation). Runoff volume was linearly related to soil moisture before a rainfall event (12). Therefore, fertilizer applications should be avoided when soils are near saturation and rain is in the forecast.

The first rain event after a fertilizer application will produce the greatest phosphorous or nitrogen transport

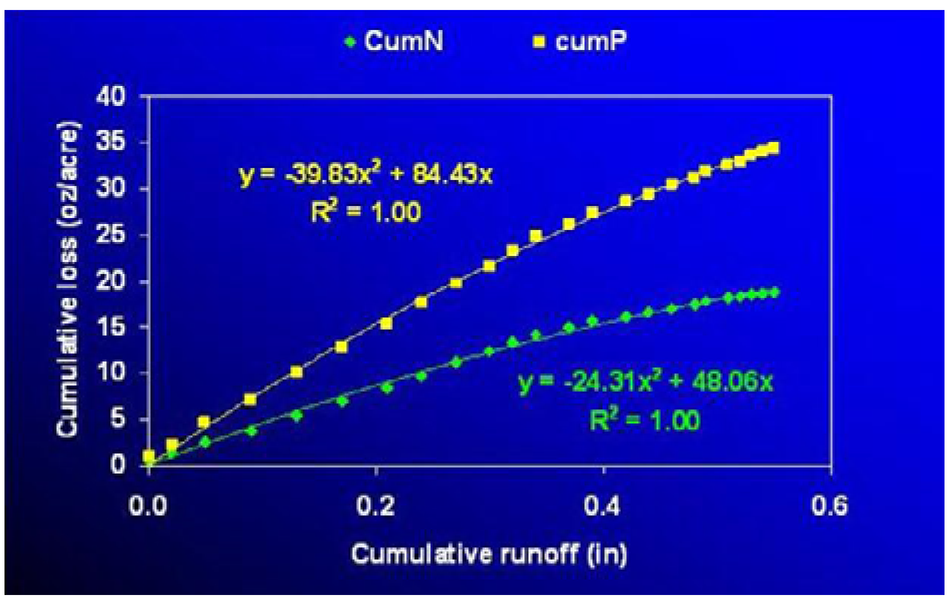


Figure 5. The amount of nutrient runoff is strongly related to the amount of natural rainfall runoff. Above, the cumulative amount of phosphorous (yellow line) and nitrogen (green line) lost (y-axis, oz. per acre) in natural rainfall is plotted with the cumulative natural rainfall runoff (x-axis, inches). Estimates were averaged for 30 rainfall events from samples taken at 5-minute time intervals following the initiation of runoff on a bermudagrass fairway study site at Oklahoma State University conducted during 2003 through 2007.

by runoff water. Lightly watering-in fertilizer will reduce transport, as should applying fertilizer when significant rainfall is not expected for several days (16).

MEASURING RUNOFF

Earlier nutrient runoff investigations utilized small plots, and it is important to know whether such small-plot results can be used to estimate nutrient loss on a watershed scale. Researchers at the University of Maryland demonstrated that plot size had no effect on total nitrogen losses found in runoff water (5). Several studies have utilized much larger plots or entire watersheds to characterize nutrient losses from golf courses (3, 4, 12, 13, 15, 19, 20). Using this approach, nitrogen and phosphorus loadings from an Austin, Texas, golf course were generally greater than or similar to losses from native prairies and forests, but less than loadings reported for agriculture (12). Large-plot research at Oklahoma State University revealed that approximately 2.5% of the nitrogen applied was lost in irrigation runoff (3).

Concerns were raised by scientists about the effect of nutrient runoff losses into surrounding streams on aquatic macroinvertebrate (insect) populations. Research at the University of Maryland was conducted to test whether such population shifts were occurring downstream from golf course watersheds. Monthly sampling did not reveal increases in downstream nutrient concentrations, and researchers concluded that golf course fertilizer applications did not appear to contribute to long-term stream nutrient enrichment or impact stream-macroinvertebrate communities (17).

REMEDIATION/MITIGATION

Although a review of golf course water quality monitoring studies indicated that widespread or repeated water quality impacts by golf courses did not occur at the sites studied, concerns were raised about phosphorus (1). It is important to determine what measures will reduce the risk of phosphorus runoff, as well as the less frequent nitrate-nitrogen runoff and leaching losses from golf course sites.

Scheduling applications around rainstorm events that favor near-term runoff is one of the most powerful management tools superintendents have at their disposal to minimize nutrient transport to surface waters (5). Research indicates that the use of controlled-release fertilizers can reduce nitrogen leaching, but do not appreciably retard phosphorus leaching (16). Because leaching of phosphorus may occur in sand-based putting greens, P-containing fertilizers should be applied only in small amounts based on soil-test recommendations (9, 10).

The use of vegetative buffer strips is an effective method to limit nutrient runoff into surface waters (2, 6, 18). Researchers at the University of Wisconsin demonstrated that fine fescue buffer strips provided runoff and leachate results similar to prairie plantings (18). Research at Oklahoma State University demonstrated that multiple-cutting-height buffers reduced P loss by 11% in natural rainfall runoff and by 14 % in irrigation runoff compared with the single-cutting-height buffers. Nitrogen loss also was reduced by 17% in natural rainfall runoff and by 18% in irrigation runoff using multiple-cutting-height buffers compared with single-cutting-height buffers (2).

Constructed wetlands can filter runoff from golf courses and effectively limit the risk of nutrient contamination. On a golf course at Purdue University, a constructed wetland efficiently removed 97% of nitrate nitrogen and 100% of ammonia nitrogen (14). The research demonstrated that the golf course wetlands could be used to filter golf course tile drains, as well as runoff from adjacent residential and business property (14).

Current research efforts include cultivation techniques to reduce runoff from turfgrass sites and the use of end-of-tile filters to remove nutrients from subsurface drainage water. As results from these studies are attained, turf managers will have additional tools to limit the amount of nutrients transported to ground and surface water from managed golf course turf.


The use of constructed wetlands to filter runoff from golf courses is another way to effectively limit the risk of nutrient contamination. In a constructed wetland on a golf course at Purdue University, the wetland efficiently removed an estimated 97% of N-NO_3/NO_2 and 100% of N-NH_3.

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Current research includes investigations involving end-of-tile filters to remove both nutrients and pesticides before drainage water is released to surrounding streams and drainage ditches.

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