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Karl Guillard

Kelly L. Kopp
Utah State University

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Nitrogen Fertilizer Form and Associated Nitrate Leaching from Cool-Season Lawn Turf

Karl Guillard* and Kelly L. Kopp

ABSTRACT

Various N fertilizer sources are available for lawn turf. Few field studies, however, have determined the losses of nitrate (NO$_3$–N) from lawns receiving different formulations of N fertilizers. The objectives of this study were to determine the differences in NO$_3$–N leaching losses among various N fertilizer sources and to ascertain when losses were most likely to occur. The field experiment was set out in a completely random design on a turf typical of the lawns in southern New England. Treatments consisted of four fertilizer sources with fast- and slow-release N formulations: (i) ammonium nitrate (AN), (ii) polymer-coated sulfur-coated urea (PCSCU), (iii) organic product, and (iv) a nonfertilized control. The experiment was conducted across three years and fertilized to supply a total of 147 kg N ha$^{-1}$ yr$^{-1}$. Percolate was collected with zero-tension lysimeters. Flow-weighted NO$_3$–N concentrations were 4.6, 0.57, 0.31, and 0.18 mg L$^{-1}$ for AN, PCSCU, organic, and the control, respectively. After correcting for control losses, average annual NO$_3$–N leaching losses as a percentage of N applied were 16.8% for AN, 1.7% for PCSCU, and 0.6% for organic. Results indicate that NO$_3$–N leaching losses from lawn turf fertilizers should be formulated with a larger percentage of slow-release N than soluble N.

Various formulations of N-based fertilizers are available for lawn turf. These products range in formulation from highly soluble, fast-release sources of N such as urea, ammonium nitrate, and ammonium sulfate to low solubility, slow-release sources such as isobutylidene diurea, coated ureas, ureaformaldehyde, or organically-based materials. Previous learning studies with cool-season turf have used soluble, fast-release N formulations (Gross et al., 1990; Harrison et al., 1993; Mittner et al., 1996; Liu et al., 1997), or a combination of fast- and slow-release N formulations (Starr and DeRoo, 1981; Morton et al., 1988; Gold et al., 1990).

It has been reported that the NO$_3$–N leaching losses from cool-season turf are higher with soluble N formulations than with slow-release formulations (Nelson et al., 1980; Moddell and Schmidt, 1985; Sheard et al., 1985; Petrovic et al., 1986; Mancino and Troll, 1990; De Nobili et al., 1992; Geront et al., 1993; Engelsjord and Singh, 1997). Other factors in addition to N solubility will affect the leaching potential from turf and these include, but are not limited to, soil type, irrigation rate, N-application rate, frequency and timing of fertilizer applications, stand density, rooting characteristics, and plant N demands (Petrovic, 1990). Results from cool-season turf leaching studies have varied considerably because of the interactions of these factors with N solubility.

There have been several reported field studies that have directly compared NO$_3$–N leaching from cool-season turf receiving fast- and slow-release N fertilizers (Sheard et al., 1985; Petrovic et al., 1986; De Nobili et al., 1992; Geront et al., 1993; Engelsjord and Singh, 1997). Of these, only the studies of Petrovic et al. (1986) and Geront et al. (1993) were conducted under lawn management conditions; the others were managed under golf or athletic field conditions. The dominant mechanisms for NO$_3$–N loss from cool-season turf seem to be: (i) late seasonal flushes associated with autumn or early-winter rain storms, (ii) excessive irrigation or precipitation exceeding evapotranspiration, and (iii) winter thaws and spring snowmelt (Moddell and Schmidt, 1985; Morton et al., 1988; Gold et al., 1990; Geront et al., 1993; Liu et al., 1997).

Traditional agricultural crop production in southern New England has declined rapidly during the last 30 yr. As urban and suburban development encroaches into rural landscapes, turf is replacing cropland as the principal managed land cover in the region. This situation is not unique to this region of the country; turf associated with suburban development is replacing cropland along the entire Eastern Seaboard of the United States. Although most turf areas are not regarded as agricultural cropland, they may receive comparable amounts of fertilizers as are applied to cropland.

There are few field studies that report NO$_3$–N leaching losses from cool-season lawn turf fertilized with various N sources. More studies are needed to determine the fate and transport of NO$_3$–N applied to turf in urban or suburban settings. Therefore, this study was conducted to determine the NO$_3$–N concentrations and losses from turfgrass managed as lawn from various forms of N and to determine the season when most of these losses were likely to occur.

MATERIALS AND METHODS

A field experiment was conducted at the University of Connecticut’s Plant Science Research and Teaching Farm in Storrs, CT, from 28 Oct. 1996 to 1 Nov. 1999. Weather data were recorded on site with a Campbell Scientific (Logan, UT)
RESULTS

Monthly and annual temperature and precipitation amounts with 30-yr normals (1971–2000) are presented in Table 1. At the beginning of the study in late 1996, precipitation was above normal. Most of 1997 had below normal precipitation on a monthly basis. Total yearly precipitation in 1998 and 1999 was closer to normal precipitation amounts, but monthly totals were highly variable. During the experimental period, temperatures...

<table>
<thead>
<tr>
<th>Month</th>
<th>Maximum temperature</th>
<th>Minimum temperature</th>
<th>Precipitation</th>
</tr>
</thead>
<tbody>
<tr>
<td>January</td>
<td>1.3</td>
<td>1.9</td>
<td>3.9</td>
</tr>
<tr>
<td>February</td>
<td>2.5</td>
<td>5.4</td>
<td>6.0</td>
</tr>
<tr>
<td>March</td>
<td>5.6</td>
<td>6.1</td>
<td>8.0</td>
</tr>
<tr>
<td>April</td>
<td>12.6</td>
<td>12.2</td>
<td>15.6</td>
</tr>
<tr>
<td>May</td>
<td>19.1</td>
<td>16.8</td>
<td>22.6</td>
</tr>
<tr>
<td>June</td>
<td>24.0</td>
<td>24.4</td>
<td>21.7</td>
</tr>
<tr>
<td>July</td>
<td>25.2</td>
<td>26.6</td>
<td>26.1</td>
</tr>
<tr>
<td>August</td>
<td>24.9</td>
<td>24.6</td>
<td>26.6</td>
</tr>
<tr>
<td>September</td>
<td>21.9</td>
<td>21.6</td>
<td>23.1</td>
</tr>
<tr>
<td>October</td>
<td>15.6</td>
<td>14.9</td>
<td>16.0</td>
</tr>
<tr>
<td>November</td>
<td>7.1</td>
<td>7.2</td>
<td>9.7</td>
</tr>
<tr>
<td>December</td>
<td>5.3</td>
<td>3.8</td>
<td>7.4</td>
</tr>
<tr>
<td>Mean or sum</td>
<td>13.8</td>
<td>13.8</td>
<td>15.7</td>
</tr>
</tbody>
</table>

Note: All 30-yr normals are close to the 1971–2000 average. The mean or sum includes the 3-yr average and the range.

Nitrate Nitrogen Concentrations

Concentrations of NO$_3^–$-N were more likely to be above the detection limit and above the maximum contaminant level (MCL) in percolate from the AN fertilizer compared with the PCSCU, organic, or control treatments (Table 2). Analysis of ranked data across three years indicated that the mean rank (approximation of the median) of NO$_3^–$-N concentration in the percolate collected from the AN fertilizer treatment was significantly greater ($p < 0.0001$) than mean rank NO$_3^–$-N concentrations from the PCSCU, organic, or control treatments (Fig. 1). Similarly, flow-weighted NO$_3^–$-N concentrations across three years from the AN fertilizer treatment were significantly greater ($p < 0.05$) than the 3-yr, flow-weighted NO$_3^–$-N concentrations from the PCSCU, organic, or control treatments (Table 3).

Nitrate Nitrogen Mass Loss

Total percolate flow was not different ($p > 0.05$) among treatments. Yearly mean percolation, as a percentage of yearly mean precipitation covering the experimental period, was 29.4% for AN, 31.2% for PCSCU, 34.9% for organic, and 33.3% for control treatments. These amounts are consistent with expected percolation values for this soil. Percolate flow occurred with seasonal regularity. Few percolate samples were collected from May through September (on only five dates), and most samples were collected from October through March (Fig. 2). Yearly NO$_3^–$-N mass leaching losses for the AN fertilizer treatment were significantly greater ($p < 0.05$) than losses of NO$_3^–$-N from the PCSCU, organic, or control treatments (Table 3). After correcting for the control, yearly mass leaching losses of NO$_3^–$-N tended to be slightly higher than normal, particularly during the winter months (November–February).

Table 2. Log-likelihood ratio $\chi^2$ tests of independence for detection of NO$_3^–$-N in the percolate ($\geq 0.05$ mg L$^{-1}$) and for percolate NO$_3^–$-N concentration frequencies above the maximum contaminant level (MCL) for drinking water ($10$ mg L$^{-1}$) for the N source leaching study at Storrs, CT.

<table>
<thead>
<tr>
<th>Treatment†</th>
<th>n</th>
<th>Detection frequency $&lt; 0.05$ mg L$^{-1}$</th>
<th>$\geq 0.05$ mg L$^{-1}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>AN</td>
<td>71</td>
<td>7</td>
<td>64</td>
</tr>
<tr>
<td>PCSCU</td>
<td>73</td>
<td>22</td>
<td>51</td>
</tr>
<tr>
<td>Organic</td>
<td>72</td>
<td>26</td>
<td>46</td>
</tr>
<tr>
<td>Control</td>
<td>73</td>
<td>39</td>
<td>34</td>
</tr>
<tr>
<td>$\chi^2$</td>
<td></td>
<td>$34.47 &lt; 0.0001$</td>
<td></td>
</tr>
<tr>
<td>$p &gt; \chi^2$</td>
<td></td>
<td>$&lt;10$ mg L$^{-1}$</td>
<td>$\geq10$ mg L$^{-1}$</td>
</tr>
<tr>
<td>AN</td>
<td>71</td>
<td>60</td>
<td>11</td>
</tr>
<tr>
<td>PCSCU</td>
<td>73</td>
<td>73</td>
<td>0</td>
</tr>
<tr>
<td>Organic</td>
<td>72</td>
<td>72</td>
<td>0</td>
</tr>
<tr>
<td>Control</td>
<td>73</td>
<td>73</td>
<td>0</td>
</tr>
<tr>
<td>$\chi^2$</td>
<td></td>
<td>$32.26 &lt; 0.0001$</td>
<td></td>
</tr>
<tr>
<td>$p &gt; \chi^2$</td>
<td></td>
<td>$&lt;10$ mg L$^{-1}$</td>
<td>$\geq10$ mg L$^{-1}$</td>
</tr>
</tbody>
</table>

† AN, ammonium nitrate; PCSCU, polymer-coated sulfur-coated urea.
Table 3. Percolate flow-weighted NO₃–N concentrations (FWC), mean yearly NO₃–N mass leaching losses, and percentage losses of N based on amount applied after correcting for losses from the nonfertilized control plots for the N source leaching study at Storrs, CT.

<table>
<thead>
<tr>
<th>Treatment†</th>
<th>FWC Mean yearly mass loss</th>
<th>Loss per year</th>
</tr>
</thead>
<tbody>
<tr>
<td>AN</td>
<td>mg L⁻¹</td>
<td>kg ha⁻¹ yr⁻¹</td>
</tr>
<tr>
<td>PCSCU</td>
<td>0.57 b</td>
<td>3.7 b</td>
</tr>
<tr>
<td>Organic</td>
<td>0.31 b</td>
<td>2.0 b</td>
</tr>
<tr>
<td>Control</td>
<td>0.18 b</td>
<td>1.1 b</td>
</tr>
</tbody>
</table>

* Significant at the 0.05 probability level.  
† AN, ammonium nitrate; PCSCU, polymer-coated sulfur-coated urea.  
§ Values within a column followed by the same letters are not significantly different (p < 0.05) based on Duncan’s new multiple range test (α = 0.05).

as a percentage of N applied (147 kg N ha⁻¹ yr⁻¹) were significantly greater (p < 0.05) for the AN fertilizer treatment compared with the PCSCU and organic fertilizer treatments (Table 3). Leaching losses of NO₃–N were negatively correlated with monthly cumulative PET (Fig. 3). Once monthly cumulative PET reached 30 mm or more, the probability of NO₃–N leaching was low.

## DISCUSSION

The loss of NO₃–N in our study was affected both by N source and by season. The results are similar to several previously reported cool-season turf studies that have shown more NO₃–N leaching losses from soluble N forms than from less soluble N forms (Nelson et al., 1980; Mosdell and Schmidt, 1985; Sheard et al., 1985; Petrovic et al., 1986; Mancino and Troll, 1990; De Nobili et al., 1992; Geron et al., 1993; Engelsjord and Singh, 1997). The NO₃–N leaching losses from PCSCU and organic treatments in our study suggest that lower solubility N fertilizers will present a much lower risk of water pollution from lawns, and will not be substantially different from losses originating from nonfertilized turf areas. Concentrations and losses of NO₃–N from the nonfertilized control treatment and the low-soluble N sources used in our study were similar to background levels (<0.20 mg NO₃–N L⁻¹) observed from percolate collected from forested landscapes in our region (Gold et al., 1990). This reinforces the recommendation that lower-solubility N sources should be used in environmentally sensitive areas or where there are pollution concerns with turf fertilization.

Percolate flow and associated NO₃–N leaching losses were primarily observed when monthly cumulative PET was <30 mm with normal or above normal rainfall periods, and following snow melt (Fig. 2 and 3). When monthly cumulative PET was >30 mm or when precipitation was below normal, few leaching events occurred. For example, in 1997 no percolate was collected during the growing season and throughout December, which was probably attributable to below-normal precipitation. Percolate flow resumed in January 1998, which had above normal temperatures and precipitation (Table 1). Our results indicate the importance of continuous sampling in turf leaching studies during all seasons. It is often presumed that once the winter season begins, the ground becomes frozen and no leaching occurs. Our data show that percolate was frequently captured during the winter and early spring months, and contributed to a significant portion of the NO₃–N losses under our conditions. The deep collection reservoirs also prevented the percolate sample from freezing during the winter before removal of the sample.

Seasonal effects on NO₃–N leaching from turf have been reported in a few previous studies. Gold et al. (1990) reported that greatest NO₃–N concentrations and leaching losses from lawn turf in Rhode Island occurred during spring snow melt. Geron et al. (1993) also observed that NO₃–N leaching losses from newly established turf in Ohio were more a function of seasonal and climatic variations (more during the winter vs. late
flow-weighted NO$_3$–N concentration across the three years was less than half the MCL. Although lower than the MCL for drinking water, the flow-weighted NO$_3$–N concentrations from the soluble AN treatment recorded in our study could be a factor in the degradation of bay and estuarine water quality (Ryther and Dunstan, 1971).

In the presence of P, NO$_3$–N concentrations as low as 0.3 mg L$^{-1}$ can prompt the development of algal blooms (Brooks et al., 1991). Nitrogen has been identified as the primary pollutant contributing to hypoxia in Long Island Sound (New York Department of Environmental Conservation–Connecticut Department of Environmental Protection, 2000), which is the largest waterbody of economical and ecological importance in our area. In coastal environments such as ours, relatively small leaching losses of NO$_3$–N from fertilized lawns may be ecologically significant by contributing to the overall N loading of the receiving waters. Whereas in other inland regions or environments where yearly precipitation is lower and winter recharge of ground water is not as great, these losses may be of less concern relative to other land uses that generate potentially greater nitrate leaching losses.

The majority of NO$_3$–N leaching events occurred from late fall to early spring in our study. Therefore, implementing a turf fertilizer program that does not result in the buildup of excess soil NO$_3$–N going into the late fall period seems prudent. A similar conclusion was reached with studies conducted in the Pacific Northwest by Miltner et al. (2001). Their data show a rapid increase of inorganic N in the soil during the late fall that was attributed to mineralization and nitrification. Plant uptake of N (as measured by clipping N concentration), however, could not keep pace with mineralization and nitrification. The result was a buildup of soil NO$_3$–N that increased the potential for leaching, especially when fertilizer N was applied.

Our N rates were based on a typically recommended practice in our area of 147 kg N ha$^{-1}$ split into three separate applications of 49 kg N ha$^{-1}$. This rate may have been more than what was needed to sustain acceptable quality at this site, because clippings were also returned. Kopp and Guillard (2002) found that the quality of the lawn turf at the same location used in this study was equivalent between a 98 kg N ha$^{-1}$ rate with clippings returned and a 196 kg N ha$^{-1}$ rate with clippings removed. The N provided by the clippings afforded the opportunity to reduce fertilizer N rates without a loss in quality. This has been reported also in another Northeast study (Heckman et al., 2000).

The agronomic benefits of late-season N fertilization of turf have been reported (Hanson and Justska, 1961; Powell et al., 1967; Wilkinson and Duff, 1972; Wehner et al., 1988; Wehner and Haley, 1993). Little is known, however, about the fate of N after late-season application and the effects on water quality. Popular perception, even among turfgrass scientists, is that late-season fertilization of lawns poses little or no threat to the environment because it stimulates rooting and rhizome activity, which is sufficient to capture the applied N. In a review on the fate of N applied to turfgrass, however, Petrovic (1990) raised caution concerning this practice.

**Figure 3.** Relationship between monthly cumulative potential evapotranspiration (PET) and monthly cumulative NO$_3$–N leaching losses for different N fertilizer treatments applied to lawn turf (AN, ammonium nitrate; PCSCU, polymer-coated sulfur-coated urea). Significance of Spearman rank correlation coefficient ($r$) is indicated at * ($p < 0.05$) and ** ($p < 0.01$).
from an environmental risk perspective, especially with soluble fertilizer formulations. Liu et al. (1997) reported that cool-season turfgrass species and cultivars grown in Rhode Island differed substantially in their N-use efficiencies, and they indicated that fall or winter fertilizer application might further enhance the leaching potential of some grasses that inherently express poor N-use efficiency.

These observations in addition to our data suggest that late-season fertilization of turf with certain soluble N formulations (particularly those containing NO3-) may increase the potential of N losses by leaching in our climate. This observation of greater leaching losses during the late fall through early spring seasons may also hold true in other coastal climates where there is greater potential for winter ground water recharge than for inland climates. Timing of N application to Kentucky bluegrass turf after establishment did not affect NO3--N leaching losses in Ohio (Geron et al., 1993) or in Michigan (Miltner et al., 1996). This is contrary to what we observed, and may be attributed to the differences in the amounts of nonfrozen precipitation received during the late fall–early winter periods between the southern New England coastal climate (more rain) and the inland continental Ohio and Michigan climate (more snow).

CONCLUSIONS

This study suggests that NO3--N leaching from cool-season lawn turf is more likely during the late fall through the early spring in southern New England than during late spring through summer. Consequently, soil NO3--N concentrations in our climate should be minimized before this leaching period to reduce the potential for leaching losses. To further reduce the threats of NO3--N leaching in coastal environments of southern New England, lawn turf fertilizers should be formulated with a larger percentage of slow-release N than with soluble N.

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