University of Kentucky
College of Agriculture, Food and Environment
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The Fate of Nitrogen Applied to Kentucky Turfgrass

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The quality of Kentucky's surface and ground waters are of utmost importance to flora and fauna living in these waters. The growth of flora and fauna is directly related to the amount of available nutrients in these waters. In addition, we use these waters as the primary source of drinking water for ourselves and our families. A wide range of compounds may be found in these waters, including nitrate (NO_3^-). The sources of nitrogen (N) may include, but are not limited to, atmospheric deposition, septic tanks, effluent water disposal, agricultural fertilization, and landscape fertilization. The objective of this publication is to identify and describe the sources and potential fates of N applied to Kentucky turfgrass.

This discussion will include five paths N may take after being applied to turfgrass. These include conversion to atmospheric gas, turfgrass uptake, soil storage, leaching, and runoff. However, it is first important to understand the contribution of turfgrass to Kentucky's fertilizer consumption. When discussing Kentucky's water quality, in particular N contamination, we must consider all the potential sources of N and their relative contributions to groundwater contamination. When all the N fertilizer applied in Kentucky is considered, the amount applied to turfgrass is comparatively low, contributing < 7 percent to the total N applied in Kentucky. Although that percentage is low relative to other markets, it is still crucial that we understand the paths that it may take in a turfgrass system. Understanding these fates will help to protect Kentucky's ecosystem and to enhance decisions regarding best management practices.

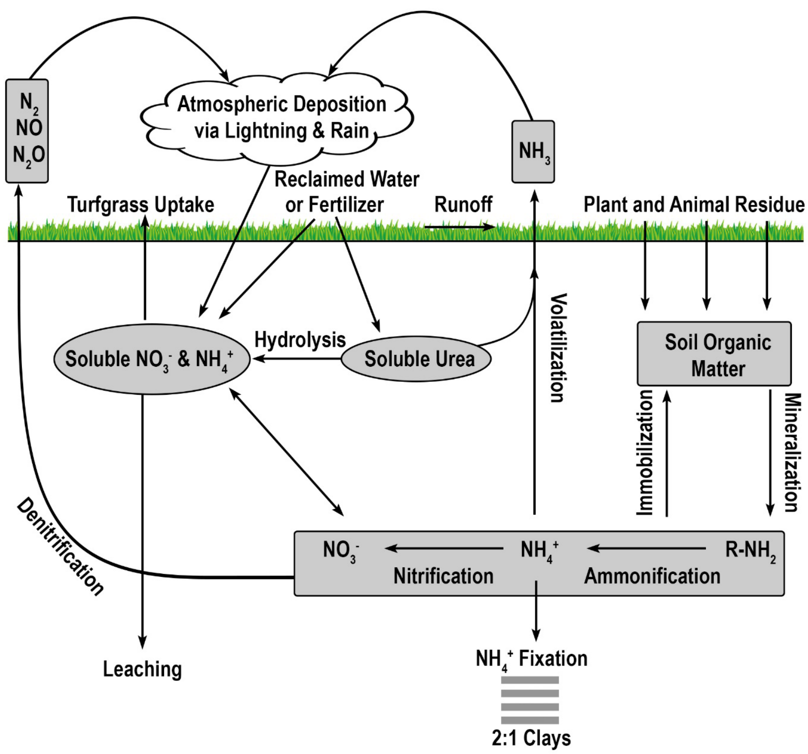

Figure 1. The nitrogen cycle in turfgrass.

Atmospheric Nitrogen

More than 99 percent of all N on planet earth exists in the atmosphere and is chemically and biologically unavailable to plants, except those which are capable of biological N fixation. Approximately 78 percent of the air we breathe is N_2 gas, which can be converted into a useable form (i.e. fertilizer) via the Haber-Bosch process or by biological N fixation. Once harvested from the atmosphere, N applied to turfgrass easily coverts back to a gas either via volatilization or denitrification (Figure 1).

Volatilization is the conversion of N to ammonia (Figure 2). The factors influencing conversion of N to a gas include quantity of soluble N as urea or ammonium, temperature, high soil pH, low soil moisture, and low cation exchange capacity. Nitrogen converted to ammonia is lost to the atmosphere and is no longer available for turfgrass uptake. While volatilization is a distinct disadvantage to the turfgrass, the loss of N as ammonia decreases the amount of N available to move into nearby water bodies via leaching or runoff. However, N volatilization may increase the amount of N returned to the earth via rainfall and atmospheric deposition. Because N is commonly applied to turfgrass as urea, volatilization can be a major contributor to N lost from turfgrass systems, with losses ranging from < 1 percent to as high as 60 percent of applied N. This percentage can be reduced by using slow-release urea, urease inhibitors, or by irrigating the turf immediately after fertilization. Slow-release N sources are defined as any N source that releases its N at a slower rate compared with a reference soluble N source. Urease inhibitors slow the conversion of urea to NH_4^+ by inhibiting urease, the enzyme necessary for urea hydrolysis to occur. In so doing, the rate of volatilization can be reduced by as much as half.

$$\underset{\textit{Urea}}{CO(NH_2)_2} + H_2O \xrightarrow{\textit{urease}} 2NH_3 + CO_2$$

Figure 2. Nitrogen volatilization converts urea into ammonia gas.

Urease inhibitors may be marketed as "nitrogen stabilizers." Numerous products marketed as urease inhibitors have been tested by land-grant institutions. Only the "nitrogen stabilizers" containing N-(n-butyl) thiophosphoric acid triamide (NBPT) or N-(n-propyl) thiophosphoric acid triamide (NPPT) have consistently reduced volatilization compared with urea alone. Slow-release N fertilizers also reduce volatilization not through urease inhibition but by delaying the release of urea into the N cycle.

Denitrification is the microbial conversion of NO_3^- to N_2 gas (Figure 3). The conditions that favor denitrification are wet, organic soils containing NO_3^-. Similar to volatilization, denitrification converts N into one of several N species: nitrite (NO_2^-), nitric oxide (NO), nitrous oxide (N_2O), or gaseous N (N_2), reducing the amount of plant-available N and the amount of N available to move to non-target locations. Denitrification requires N to be in the NO_3^- form, which is then reduced as oxygen is removed. Denitrification is greatly influenced by increased soil moisture, which results in an oxygen-deprived soil and hastens the removal of oxygen from NO_3^- by denitrifying bacteria. When soil oxygen levels drop below 2 percent, denitrification is increased. However, denitrification may still occur in aerated soils due to the saturation of internal soil microsites. Turfgrass studies designed to determine denitrification rates in Kentucky are limited. However, soils with appreciable quantities of clay tend to poorly drain, resulting in substantial N loss via denitrification. On sandy soils such as those on sand-based putting greens, denitrification is normally low and accounts for < 1 percent to 5 percent of applied N but could approach 94 percent when temperature exceeds 30°C. Because denitrification in Kentucky soils can be high, nitrification inhibitors and/or slow-release N sources can be useful. Nitrification inhibitors should contain either 2-chloro-6(trichloromethyl) pyridine (Nitrapyrin) or dicyandiamide (DCD), as these are the only two compounds that have reduced denitrification in field and laboratory studies. Similar to their effect on volatilization, slow-release N fertilizers may reduce denitrification by delaying the release of their N into the N cycle.

$$NO_3^- \rightarrow NO_2^- \rightarrow NO \rightarrow N_2O \rightarrow N_2$$

Figure 3. Denitrification—NO_3-N subject to reduction by soil microbes leading to N_2.

Turfgrass Uptake

The objective of all N applications to turfgrass is sustainable plant uptake and the resulting increase in turfgrass growth, green color, or visual quality. Numerous factors may influence turfgrass uptake of N, including (but not limited to) turfgrass species, season, N type, N rate, and moisture management.

The percent of applied N recovered in turfgrass varies depending upon turfgrass species and the location sampled on the plant. Species that possess a greater density of roots deeper in the soil profile tend to take up greater amounts of applied N compared with turfgrasses with less dense root systems. Clearly, greater uptake occurs because a turfgrass with a greater quantity of roots has an increased chance for its roots to intercept and uptake N.

Like most plants, the change in climatic seasons (e.g. spring, summer, autumn) can have a dramatic influence on plant growth and nutrient uptake. During the winter, warm-season turfgrasses enter dormancy (a natural turfgrass phase in which the plant is alive, but no cell division or elongation occurs). As turfgrass growth declines, the amount of N needed by the turfgrass also declines. Thus, consumption of applied N by warm-season turfgrass is lower in the winter than in the summer. Inversely, cool-season grass grow best in autumn and spring and exhibit reduced growth in winter and summer. N applications to dormant or semi-dormant turfgrass has not resulted in N leaching unless excessive rainfall occurs, thus the applied N will remain in the soil until the plant consumes it or until rainfall/irrigation moves the N beyond the rootzone. However, the agronomic advantages to applying N to dormant turfgrasses are low relative to the environmental risk. Thus, N applications to dormant turfgrasses in Kentucky are not recommended.

Nitrogen fertilizers differ in their form of N and their release characteristics. These differences can lead to different quantities of N absorbed by turfgrass. Nitrogen applied as NH_4^+ may result in less N uptake than N applied as NO_3^- due to the tendencies of NH_4^+ to volatilize and be lost from the soil/turfgrass system. A larger percentage of N from slow-release N fertilizers may be taken up by the turfgrass compared with soluble N sources. Soluble N is immediately available to follow any of the potential paths in the soil/turfgrass system, including leaching and volatilization, whereas only small portions of N from slow-release N fertilizers become soluble at any given time. To this end, slow-release N fertilizers can increase N uptake by as much as 300 percent compared with soluble N sources.

A driving factor behind the University of Kentucky nutrient recommendations to turfgrass is to apply the amount of N necessary to achieve a desired turfgrass response without applying more N than the turfgrass can consume at any given time. When the University of Kentucky recommended N rates are followed, turfgrass uptake of applied N ranges from 40 to 68 percent and may approach 80 percent under certain conditions. When small quantities of N are applied, very little N has an opportunity to escape turfgrass assimilation. As rates of soluble N increase, the percentage of applied N recovered in turfgrass tissues decreases. However, slow-release N sources often require higher application rates compared with soluble N sources in order to achieve the same desired turfgrass response because only a small portion of the slow-release N will become soluble on a daily basis. Consequently, higher rates of slow-release N sources may result in greater percent uptake of applied N than lower rates. In addition, a single application of slow-release N at a high rate may result in the same N uptake as soluble N applied as a split application. Therefore, slow-release N sources may be applied at higher rates than soluble N sources so long as the single application rate and total annual N applied do not exceed the University of Kentucky recommendations.

Moisture management greatly influences plant uptake of applied N since the majority of N is taken up by the plant via the soil solution. Thus, when the soil water content exceeds the soil water holding capacity, N in the soil solution may be moved below the rootzone, resulting in reduced plant uptake. When insufficient water is applied, however, the turfgrass may enter a state of drought-induced dormancy in which the turfgrass reduces water and N uptake in order to survive. Thus, careful consideration should be given to applying sufficient water to maintain acceptable turfgrass but not applying more water than can be retained by the soil. Generally, rain sensors, soil water sensors, and evapotranspiration controllers apply water more effectively than automatically timed controllers.

Soil Retention, Immobilization, and NH_4^+ Fixation

The amount of N stored in the soil is dependent upon many factors, particularly fertilizer type, fertilizer rate, time of year, soil moisture, soil pH, and rainfall. The majority of soil N exists as organic N in the form of organic matter or as N that has not been released from slow-release fertilizer granules. Technically, fertilizer granules are not a component of soil-stored N. However, the process of measuring soil N (combustion or digestion) will also measure N from any fertilizer granules that have not yet been released. The type and amount of slow-release fertilizer will directly influence this value. Once released from the slow-release form, N may remain in the soil via anion or cation exchange. The cation exchange capacity of most Kentucky soils is normally high (~15 cmol [+] per kilogram of soil), and the anion exchange capacity is normally too low to measure. In Kentucky soils, mineralized N, N applied as urea, or N applied as NH_4^+ can rapidly convert to NO_3^- and, because NO_3^- is an anion, it is not retained by the soil. Thus, soil storage of N via cation exchange is commonly less than 10 percent of applied N and can be less than 2 percent.

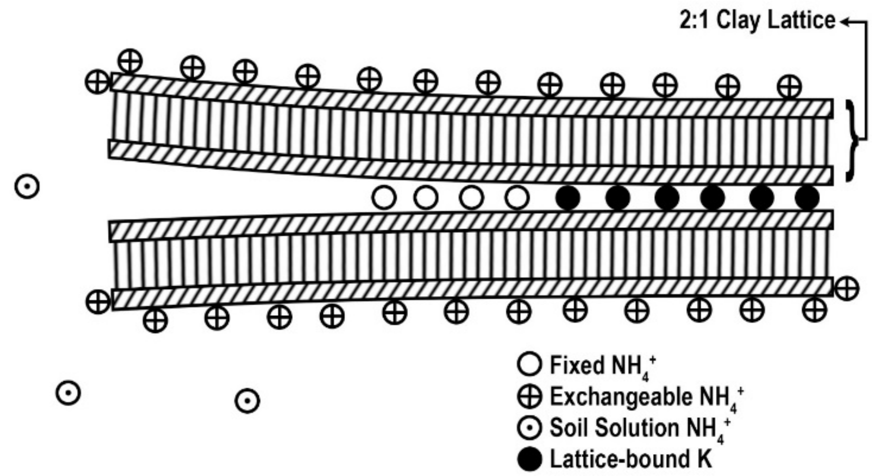

Figure 4. Ammonium may become fixed within the lattice of 2:1 clays and be rendered unavailable for turfgrass uptake. Figure modified from Strand, 1998.

Nitrogen immobilization occurs when inorganic N is converted to organic N via microbial activity. An organic form of N is simply any form of N that is bound with carbon. Like plants, microbes require N to survive and some portion of applied N will be consumed by microbes and converted into amino acids, proteins, or some other organic form used for growth by the microbes. While in an organic form, N is not soluble and therefore is unavailable for plant uptake or loss to a water body. Organic N will remain unavailable for plant uptake until the environmental conditions change to favor N mineralization. The percentage of applied N that becomes microbially immobilized in turfgrass systems will vary according to numerous factors including soil moisture, pH, and soil temperature. Little, if any, research has been conducted to determine immobilization of applied N in Kentucky turfgrass systems. Thus, providing an estimation is difficult. However, research conducted on turfgrass in cooler climates (Connecticut on a relatively sandy soil) reports that N immobilization may range from 15 to 26 percent of applied N.

Ammonium fixation occurs when NH_4^+ enters the layer (lattice) of a 2:1 clay (Figure 4), becoming unavailable for plant uptake. Ammonium fixation in Kentucky soils may be significant because the content of 2:1 clays in Kentucky soils can be high. The exact percentage of applied N to Kentucky turfgrasses that eventually is fixed by 2:1 clay minerals is unknown. However, evidence indicates the percentage is less than 5 percent.

Leaching

Leaching is the process that moves soluble N below the rooting zone. Nitrogen leaching in turfgrass systems occurs at the moment soluble N moves below the deepest root. When turfgrass is fertilized according to the University of Kentucky recommendations, N leaching is normally low. As with other fates of applied N, the exact amount of N that will leach is difficult to determine. However, it is possible that 0 to 55 percent of applied N could be leached, with the higher percentages occurring when the University of Kentucky recommendations are not followed. When N leaching does occur, it is usually a factor of the turfgrass species, irrigation management, N source, N rate, or stressed turfgrass.

The influence of turfgrass species on N leaching losses is largely a factor of the turfgrass root system. Deeper rooted turfgrasses such as tall fescue tend to reduce N leaching losses compared with shallow-rooted turfgrasses. Management practices that encourage deep rooting, such as deep, infrequent irrigation, are factors that shape the University of Kentucky recommendations. Increased N leaching has been documented when N is applied within the first 60 days of planting sod. After the sod has been planted for 60 days, N leaching is reduced and is a result of increased root growth. Therefore, it is suggested that N applications to newly sodded turf commence 60 days after the sod has been planted. This suggestion allows the sod to develop a root system prior to fertilization and thus minimizes the risk of N leaching. Likewise, fertilizer should be held off from newly seeded or sprigged turfgrass areas until a sufficient root system is produced. In general, sprigs may be fertilized beginning seven days after planting and seeded turfgrasses beginning fourteen days after sowing.

The movement of water through the soil has a profound influence on N leaching. Once any nutrient becomes soluble in the soil solution, that nutrient is subject to the movement of water. Therefore, it is crucial to minimize any movement of water beyond the turfgrass rootzone. Increased water movement may be a result of excessive irrigation or fluctuations in rainfall due to changing seasons, which may result in more water being applied to the soil than the soil can retain.

When applied according to the University of Kentucky recommendations, soluble N may not leach more N compared with N lost naturally from unfertilized turfgrass or from fallow soil. In addition, slow-release N sources further reduce N leaching losses compared with soluble N sources. Essentially, slow-release N sources delay the release of N into the N cycle (Figure 1). Over time, small portions of N are released, which increases the likelihood of plant uptake of applied N and decreases potential for N leaching losses. Blending soluble N sources with slow-release N sources also results in reduced N leaching losses. Generally, differences in N leaching losses among slow-release N sources are negligible assuming they are applied at the same time and rate. However, differences in N release rates within polymer-coated ureas can be substantial with the faster release PCUs resulting in greater N leaching than the slower release PCUs. Enhanced efficiency fertilizers, such as nitrification and urease inhibitors, do not delay the release of N into the N cycle and thus result in similar N leaching losses as other soluble N sources.

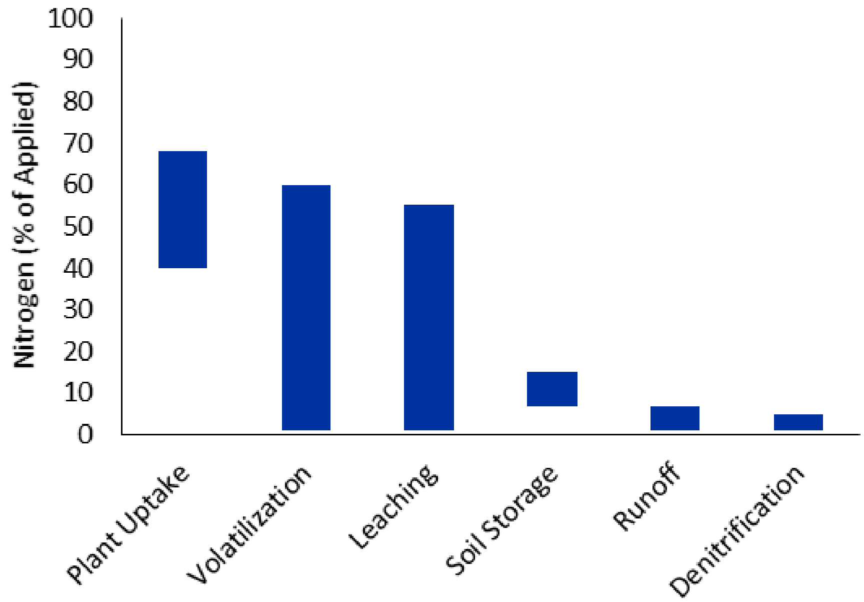

Figure 5. Range of potential fates of nitrogen applied to Kentucky turfgrass relative to the percentage of applied nitrogen.

Increasing the rate of applied N beyond the rate recommended by the University of Kentucky can increase the risk for N leaching losses. The University of Kentucky turfgrass nutrient recommendations take into account the turfgrass need for N and the potential impact on the environment. These recommendations are often 50 to 75 percent less than the amount of N necessary to increase N leaching losses above the natural environment. Thus, current rates are considered conservative, and exceeding these rates is unnecessary because any further increase in turfgrass growth or quality is minimal and could come at a cost to the environment.

As previously mentioned, N applied according to the University of Kentucky recommendations to healthy, growing turfgrass has a low probability of leaching. However, when turfgrass is stressed, N leaching can increase. Normally, stresses manifest themselves as reductions in turfgrass density and growth, which correspond to a reduction in N uptake. These stresses are largely environmental, caused by pests, late-season frosts, and changes in season. However, stresses can also be anthropogenic, caused by misapplications of nutrients or pest control products. When stresses occur, further applications of N may not cure the problem and may, in fact, exacerbate the problem and increase N leaching.

Runoff

Runoff is defined as the lateral movement of N beyond the target location. Runoff may occur above or below the soil surface but always occurs above the deepest root. At the moment that N moves below the deepest root, further movement of N is defined as leaching. Leached N may then runoff if the leached N encounters a subsurface barrier, but the N lost from the turfgrass system is considered leached if the N moved vertically beyond the rootzone. Nitrogen lost via runoff may be influenced by topography, soil type, soil compaction, soil moisture, rainfall, and fertilizer type. Because Kentucky soils contain large quantities of clay and have a relatively low water infiltration capacity, the movement of water across the soil surface can be more common than the movement of water into the soil. Runoff studies conducted on Kentucky turfgrasses are few. However, on topographies and environments similar to Kentucky, studies indicate that N runoff from turfgrass may range from 0 to 7 percent.

Summary

The fate of N applied to Kentucky turfgrass may vary greatly depending upon numerous factors. Essentially all N used in turfgrass management originated from the atmosphere and will eventually return to the atmosphere. During this cycle, ranges of the potential fates of applied N to Kentucky turfgrasses are approximated in Figure 5.

Reference

Strand, L. 1998. Remineralisation and defixation of soil nitrogen: Examensarbete. Sveriges Iantbruksuniv, Uppsala.

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