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Turf Grass TRENDS

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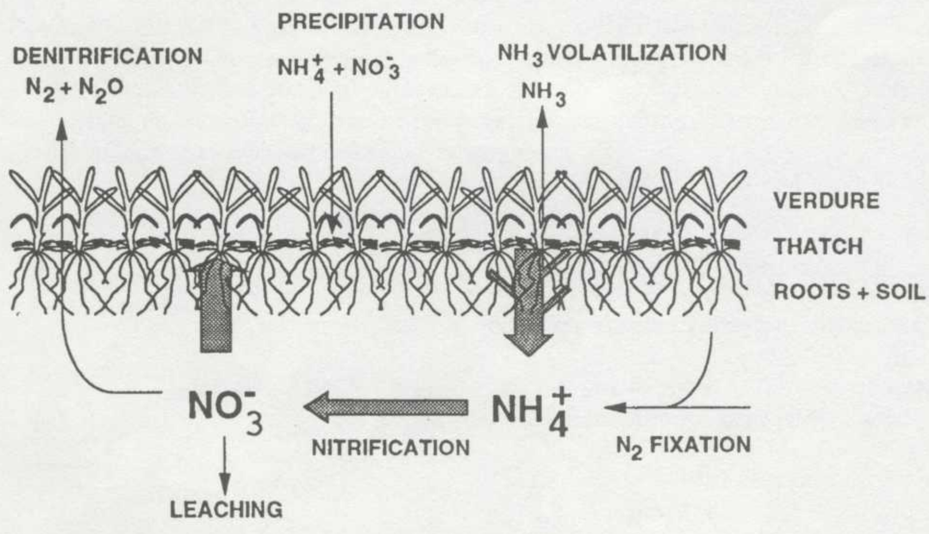
Nitrogen fate

What happens to it and where does it go?

by Dr. Richard Hull

The appetite of turfgrasses for nitrogen seems to be insatiable. It does not matter how old or how young the turf stand may be or what type of nitrogen source is applied to it; turfgrasses love nitrogen. So much so that, given the opportunity, they will take in more nitrogen than they can use, often to their own detriment. Yet, if a nitrogen fertilizer application is missed, the turfgrass will often go off color. In fact, only about 80% of the fertilizer that is applied

Nitrogen cycle in the turf-soil ecosystem



All natural inputs and losses of nitrogen are identified as well as chemical transformations. Mineralization of soil organic nitrogen is not shown nor is fertilizer input.

Figure from Hull, Alm and Jackson, 1994. Toward Sustainable Lawn Turf. p. 3-15. In A.R. Leslie (ed.) Handbook of Integrated Pest Management for Turf and Ornamentals, Lewis Pub. Boca Raton, FL.

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by turfgrass managers to turf stands can actually be accounted for in the turfgrass environment. This means that about 20% of the applied nitrogen is lost by some mechanisms other than plant use.

Where does the majority of the nitrogen go?

I and many of my fellow researchers, who are studying the fate of applied nitrogen in the turfgrass environment, have been trying to identify all of the mechanisms by which these losses take place. Certainly removal of clippings, which can contain the nitrogen equivalent of 75% of that applied as fertilizer, from the turfgrass canopy can explain the major portion of the nitrogen use. However, when the clippings are not removed and remain in the turfgrass environment, research has only been able to explain the aforementioned 20% loss.

This fact implies that as much as 80% of the fertilizer that is applied each year should still be there at the end of the year and that this accumulated nitrogen could eventually lead to a substantial reduction in the annual amount of nitrogen that is applied to a site. Although researchers are beginning to gather data that suggest that nitrogen may be accumulating in the turfgrass environment, as of this writing there has been little evidence that would lead to such reduced application recommendations forthcoming.

This mystery of the unaccounted for nitrogen is becoming the subject of much active research by many turfgrass nutritionists and turf management specialists. The research has not progressed to the point where definite answers to this question will soon be developed, but it is providing enough data that we are beginning to understand the scope of the question. In other words, we think that we now know enough to ask the right questions.

Since the results of this research may well change the way turfgrass managers use nitrogen fertility in the near future, it might be useful to examine what we do know about the fate of nitrogen in the turfgrass environment.

Turf can accumulate nitrogen

by Dr. Richard Hull

If clippings are retained and all other mechanisms of loss can account for only 15% to 20% of nitrogen applied as fertilizer to the turfgrass environment, the question remains: Where does the remaining 80% to 85% of the nitrogen accumulate?

To answer that question, we conducted a study where we collected six-inch cores of turf and separated them into their component fractions — shoots, roots, thatch, and soil. Each fraction was analyzed for total nitrogen. The table below contains the results of that analysis.

The turf used in this analysis had received 3.5 pounds nitrogen per 1000 square feet per year for three years prior to the core samples being taken. Before initiating high management practices at this site, it had been in turf for more than 25 years under varying fertility levels.

Our research into the organic nitrogen dynamics of the turf-soil ecosystem is on going, with an emphasis on determining the rate at which nitrogen accumulates in the soil fraction and what part the rate of mineralization of soil organic nitrogen plays in that accumulation. These values must be known before turfgrass managers will be able to capitalize on accumulated soil nitrogen and subsequently reduce the amount of applied fertilizer.

Nitrogen distribution within the turf-soil ecosystem

Intensively managed turf (3.5 pounds nitrogen per 1000 square feet per year)*

Turf fraction	**Total nitrogen**		**Percent of total**
	pounds per acre	pounds per 1000 square feet	%
Soil	1811	41.2	83.2
Thatch	257	5.8	11.8
Shoots	94	2.1	4.3
Roots	15	0.3	0.7
Total	2177	49.4	100.0

* Turf sampled April, 1993

It all comes down to nitrates

From a turfgrass plant's point of view, it makes little difference what source or form of nitrogen a turfgrass manager may apply, be it inorganic nitrogen salt, a coated product, or natural organic. Before the plant can benefit from the fertilizer, the nitrogen must be in a form that the plant can utilize, often the nitrate form. The nitrate and ammonium forms of nitrogen are the only two forms that the turfgrass root system can use.

If a "fast-release" inorganic nitrogen salt, such as ammonium sulfate, is applied as a fertilizer source, the salt's components dissociate in the soil water, directly releasing ammonium and sulfate into the soil solution, where they are immediately available for plant use.

If a "slow-release" nitrogen source is applied, it is often in an organic form, either synthetic or natural organic. Organic nitrogen sources are forms of nitrogen that have been "built" into complex chemical structures along with carbon, hydrogen, and oxygen. These organics range in complexity from the relatively simple water-soluble synthetic organics, such as urea and methylene urea, to the much more complex water-insoluble synthetic urea formaldehyde and the naturally-occurring organics, such as those derived from composted sources. Whether they are relatively simple organics or highly complex, they are basically similar in chemical form and are subject to the same processes.

Mineralization and nitrification

Once applied, organic nitrogen fertilizers are subject to two basic processes, mineralization and nitrification.

Mineralization: Organic nitrogen sources are utilized by microorganisms as a food source. In the process of digesting the organic nitrogen compounds much of the

Gaseous nitrogen losses

by Dr. Richard Hull

In our search for routes of nitrogen loss from the turfgrass environment, we measured loss by nitrate leaching and clipping removal. In addition, we monitored gaseous losses which can occur under very specific conditions.

Gaseous ammonia losses

Within the first 48 to 72 hours after an application of fertilizer, some nitrogen can escape as gaseous ammonia. This can occur when urea, the nitrogen source most closely identified with this phenomenon, experiences rapid mineralization either within the thatch layer or on leaf surfaces. If the ammonia that is produced is not quickly dissolved in water, producing ammonium ions, ammonia will be lost into the atmosphere.

Depending on the nitrogen source applied and the application technique used to apply the fertilizer, losses by ammonia volatilization can be substantial. These losses can reach 25% to 30% of the amount of nitrogen applied, with some researchers reporting losses that approach 50%.

Losses of gaseous ammonia into the atmosphere can be minimized by applying water immediately after an application of fertilizer. In our studies, when we did that, we observed very little ammonia volatilization: only about 1% of the nitrogen applied.

Mineralization of nitrogen within the soil profile is not subject to ammonia volatilization, because with sufficient soil water available and under the slightly acidic conditions of soil, the ammonia is rapidly trapped as ammonium ions.

Other gaseous losses

In addition to nitrogen losses as ammonia gas, saturated soil can lose nitrogen by a different process. When normally well aerated soils are waterlogged, the nitrate present can become chemically reduced by the activity of microorganisms to form elemental nitrogen and nitrous oxide. Both of these compounds are gaseous and are rapidly lost into the atmosphere. The gaseous loss occurs when the soil is saturated for several hours, soil temperatures are warm and nitrate is present.

We have measured the potential for denitrification in saturated turf soils and found that it occurs at reasonable rates. When we calculated the total nitrogen losses that can occur during times when soil is saturated, usually the 24 hours following a heavy rainfall, we found that about 5% of the nitrogen applied was lost over the course of a year.

nitrogen is released as an ammonium ion (NH_4^+) as in the following chemical reaction:

$$2CO(NH_4)_2 + O_2 + 4H^+ \longrightarrow 2CO_2 + 2NH_4^+$$

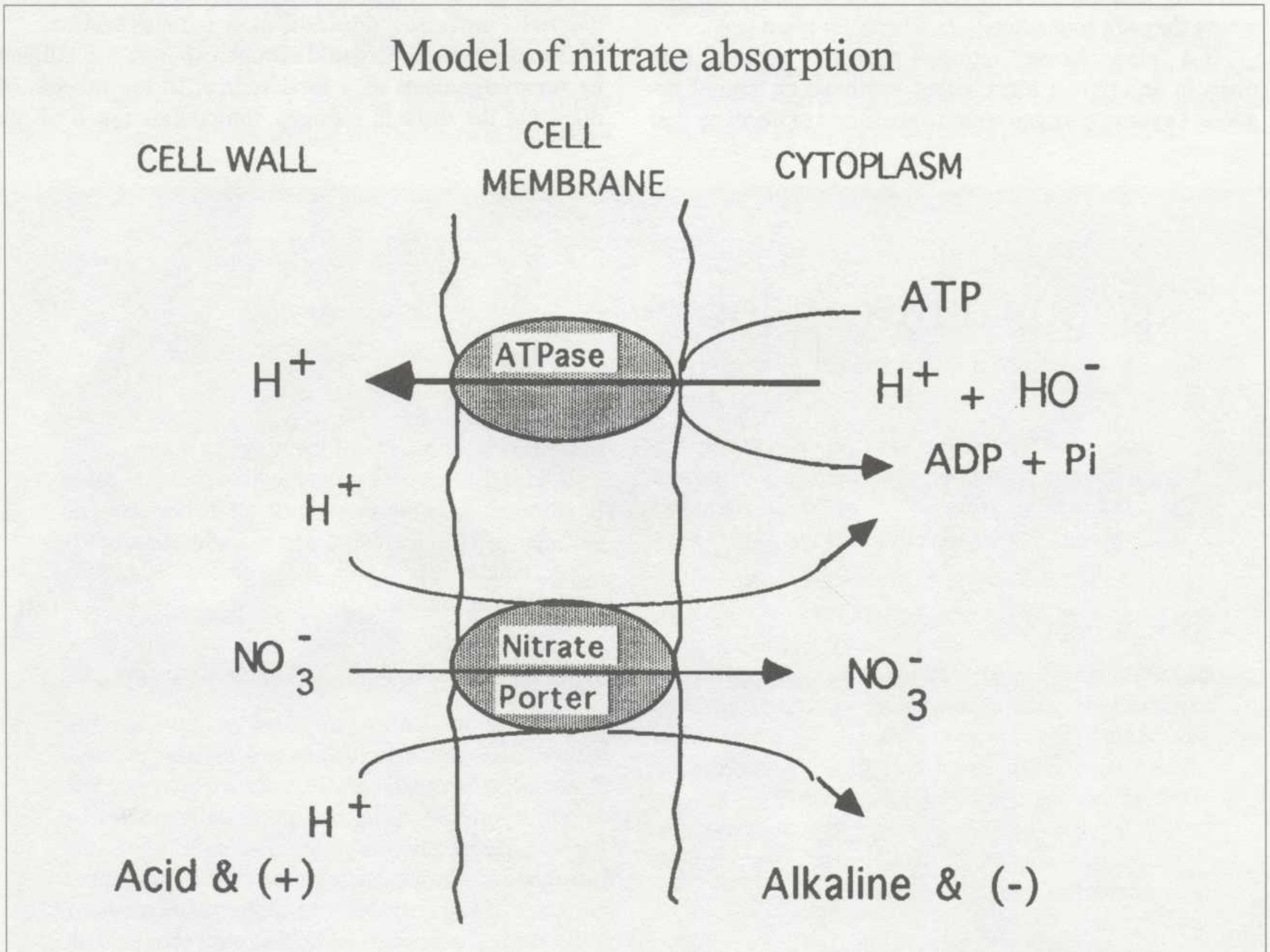
This reaction represents the oxidation of an organic nitrogen source, urea, into carbon dioxide and ammonium. This conversion of an organic nitrogen source into an inorganic ammonium-nitrogen source is an example of the process of mineralization. All organic sources, whether they are synthetic or natural, undergo this mineralization either by action of soil microbes or by chemical hydrolysis to release ammonium into the soil solution. In addition to applied nitrogen sources, naturally occurring soil organic matter also is subject to this process, liberating additional ammonium into the turfgrass environment.

Nitrification: Ammonium is available for use by both plants and soil bacteria. When ammonium is absorbed by plant roots it is incorporated into the plant in the form of important nitrogen compounds such as amino acids, proteins, and nucleic acids.

However, ammonium can also be utilized as an energy source by specialized soil bacteria in a process known as nitrification, as in the following chemical reaction:

$$2NH_4^+ + 5O_2 \longrightarrow 2NO_3^- + 4H_2O$$

This reaction represents the oxidation of ammonium into nitrate ions (NO_3^-) and water. The nitrifying bacteria intercept the majority of the ammonium liberated by the mineralization process, before it can be absorbed by the turfgrass roots. As a result, the nitrate form of nitrogen is left by default as the primary form of nitrogen that is available to be absorbed and utilized by the plants.



A model of nitrate uptake by root cells. The H^+ gradient across the cell membrane produced by ATPase is used by the nitrate porter to carry NO_3^- into the cell along with 2 H^+.

Figure provided by Dr. Richard Hull, Rhode Island University

Why does nitrogen leach from soils?

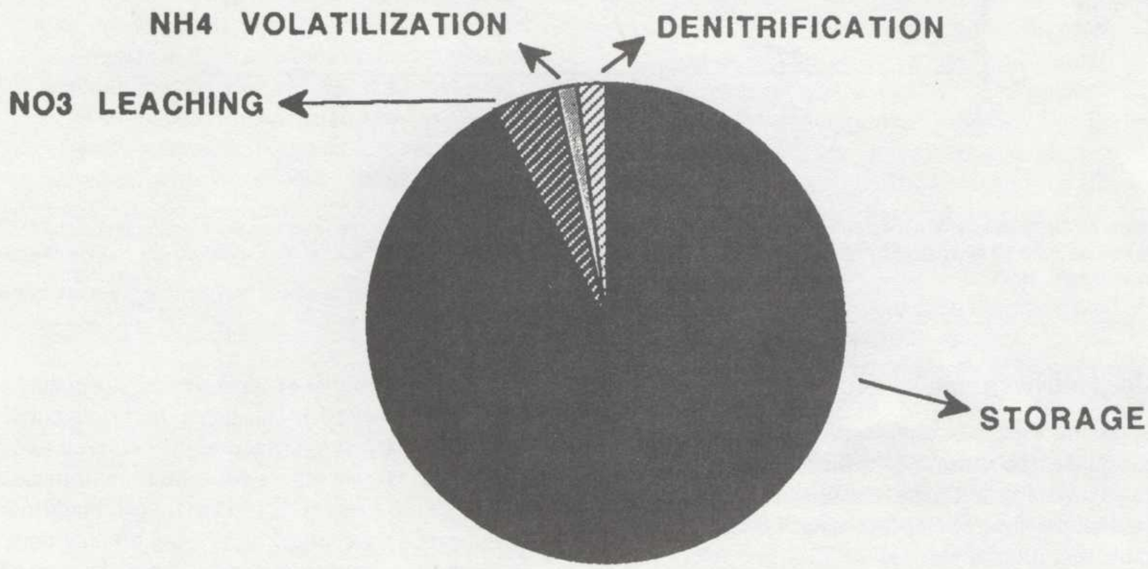
Nitrate ions (NO_3^-), relatively small and having a negative charge, are not electrically attracted to the fixed, negatively charged soil particles that normally bind many other of the positively charged plant nutrients, such as calcium, to the soil colloids in a process called cation exchange. As a result of this failure to bind to these sites (note: like negative charges repel), the nitrate is free within the soil solution and susceptible to leaching down through the soil profile below the root zone and into the ground water. This makes nitrates a potential ground water pollutant that can contaminate wells and drinking water supplies.

The major process by which nitrates are removed from the soil solution is by root absorption. Consequently, the amount of nitrates in the soil solution at any given moment is the difference between that which is released through fertilization and decomposition of naturally occurring organic matter and the amount of nitrates that are being absorbed by plant root structures.

This soil-water concentration of nitrates is an excellent measure of the balance between production and removal, and is a measure of the potential for nitrogen leaching. Low soil-water nitrate levels indicate that the nitrate produced is being absorbed by the turfgrass root system and that the potential for leaching is low. High soil-water nitrate levels indicate that production exceeds the turfgrass root system's ability to absorb the nitrogen and that the potential for leaching is high.

Whether leaching actually occurs is a function of the potential for leaching, high or low, the amount of additional water that enters the turf environment, and the porosity of the soil. Sandy soils have been identified, by several research studies, as having the greatest potential for leaching with heavier soils offering little potential. Most leaching will occur from sandy soil sites that have high soil water nitrate levels and get sufficient rainfall or irrigation water to percolate down through the soil profile, carrying the excess nitrates. These sites may have little or no leaching if excess water is delayed until the production and absorption of nitrates achieves a better balance.

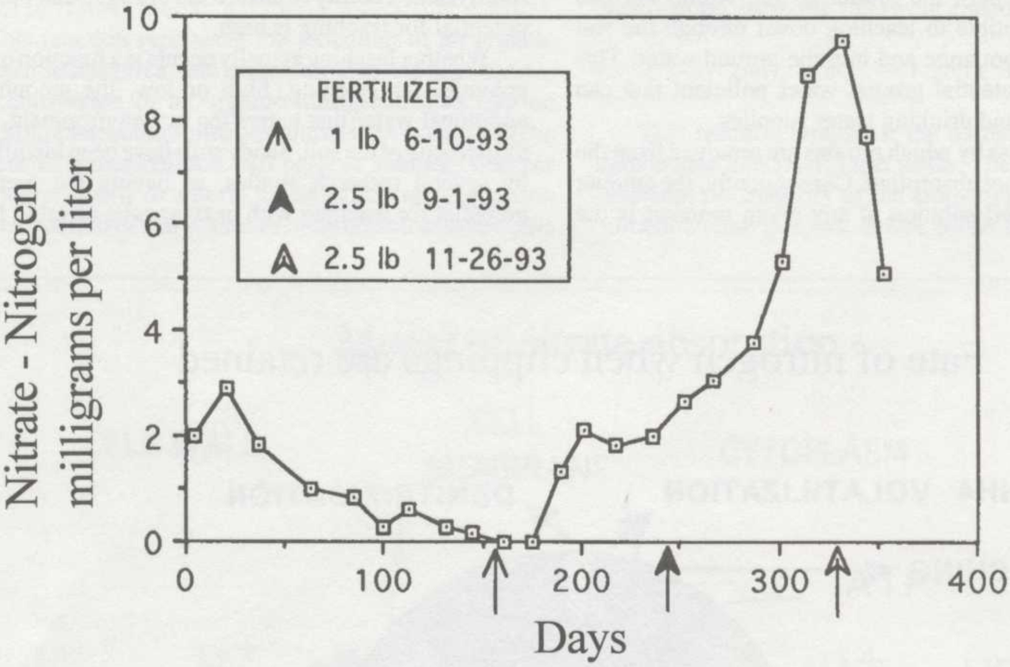
Fate of nitrogen when clippings are retained



More than 80% of the nitrogen is retained in the turf-soil system as plant tissues, thatch, and soil organic matter. This nitrogen can be viewed as in storage because it will eventually become available to turfgrass plants.

Figure provided by Dr. Richard Hull, Rhode Island University

Soil water nitrate concentrations at two feet under turf level, 1993



The yearly profile of soil water nitrate concentrations two feet under established turf. All plots received one pound nitrogen per 1000 square feet on June 10 and half of the plots received 2.5 pounds nitrogen on September 1. The other half received 2.5 pounds nitrogen on November 26, 1993.

Figure provided by Dr. Richard Hull, Rhode Island University

How does nitrogen uptake occur?

Despite the turfgrass plant's propensity for excess nitrogen uptake, the process by which the plants absorb nitrogen is anything but simple. Considering all of the obstacles that the absorption process must overcome, it is remarkable that it takes place at all.

Nitrate absorption occurs at the outermost layer of root cells, the epidermis. Despite the fact that turfgrass roots can be up to a foot in length, only the first one to two inches of the root tip efficiently absorb nutrients. If the root tips are damaged, diseased, or missing, the amount of nitrate absorption can be severely restricted.

Once at the root tip, the nitrate must overcome two important conditions to be absorbed by the root: an unfavorable nitrate ion concentration gradient and an electrical gradient. The nitrate ion concentration gradient occurs, because the nitrate concentration within the cells of the root tip is normally higher than the concentration of nitrates in the soil-water. Ions do not freely travel across a membrane, from an area of low concentration to an area of high concentration. Normally, they travel from high to low to achieve a balance. The electrical gradient occurs when the normal functioning of the roots causes hydrogen ions (H^+) to be pumped into the outer cell walls of the epidermis and the surrounding soil-water. This process occurs through the controlled hydrolysis of adenosine triphosphate (ATP) (See Figure 1 on page 4.). This leaves high concentrations of positively charged hydrogen in the cell wall and soil-water. And it leaves a higher concentration of negatively charged hydroxide ions (OH^-) within the cell in addition the existing negatively charged nitrate and organic ions.

In order for nitrate absorption to succeed against these two formidable forces working against the absorption, a third process must be at work. That is exactly what happens.

A protein imbedded in the cell membrane allows two hydrogen ions to return to the cell cytoplasm, if they are accompanied by a single nitrate ion (See Figure on page 4.). This cotransporting protein uses the energy represented by the hydrogen ion gradient across the cell membrane to drive the nitrate ion into the cell against both the ion concentration and the electrical gradient. This cotransport will succeed as long as the energy propelling the two hydrogen ions into the cell is greater than the energy keeping the single nitrate ion out.

How important are functioning roots?

How does all this chemistry relate to nitrate use by turfgrasses? For nitrate uptake to occur in turfgrass roots, metabolic energy, in the form of ATP, must be expended.

In other words, nitrate absorption can only occur in the presence of metabolically active and growing roots. ATP, in the roots, comes from the respiratory metabolism of sugars, which have been transported from the leaves to the roots. Thus for roots to be metabolically active and create the ATP that allows for the absorption of nitrates by the roots, they must be receiving sugars from the photosynthetic activity of healthy functioning leaves.

Dormant, damaged, or stressed turf leaves cannot support actively growing roots and in turn support the least amount of nitrate absorption. While robust, healthy leaves support the greatest amount of nitrate uptake. This is supported by the fact that nitrate uptake has been measured to be the highest in the spring and the lowest in the late summer.

This relationship between leaf activity and root activity would imply that rapid shoot growth and rapid root growth should go hand in hand with high nitrate uptake. Although some times true, periods of rapid leaf growth often sup-

Field tips

Steps to reduce nitrogen leaching

by Dr. Richard Hull

The experimental results suggest several nitrogen conservation practices that can be used by turfgrass managers to reduce the potential for nitrate leaching into ground water at their managed sites.

Although much research remains to be done, turfgrass managers should be able to combine these proposals with site specific information on soils, grade, etc., with current cultural practices on mowing and irrigation to significantly reduce nitrate leaching.

The over-riding principle of reducing nitrate leaching is to make fertilizer applications when the turfgrass roots can absorb it and when mineralization of naturally occurring organic matter is inadequate to meet plant needs. In cool-season turfgrass species, this can be accomplished by:

- Applying nitrogen in the early and late spring, when turfgrass roots can best use the nutrients and soil nitrate levels are likely to be low.

- Use moderately available nitrogen sources, such as urea, polymerized polycoated urea with 50% water soluble nitrogen, short-chain methylene urea or urea formaldehyde, or fortified composted materials (5-8% nitrogen). Avoid nitrogen salts, as they may release nitrates faster than root structures can absorb them or straight composts as they usually do not contain sufficient nitrogen and the mineralization can be inconsistent. Some of the organic extracts which are sold to promote root growth due to their hormonal properties may deliver sufficient nitrogen but rarely are cost effective.

- Do not apply more than 1/2 pound nitrogen per 1000 square feet at a time. That should boost the soil water nitrate level enough to supplement what the soil is delivering, but not provide much opportunity for leaching. Early spring applications may be as high as one pound nitrogen per 1000 square feet, if soil nitrate levels are low and grass is showing signs of nitrogen deficiency.

- Late summer may be a good time to apply 1/2 pound nitrogen per 1000 square feet or less if grass looks bad due to excessive loss of roots during the summer. Since the root system must regenerate from the crowns and rhizomes contained within the top 1/2 inch of soil or thatch, the plants' ability to use the abundant soil nitrate may be limited. Light applications at this time may be helpful.

- Late fall applications of nitrogen should not exceed 1/2 pound nitrogen per 1000 square feet, if the grass appears to be nitrogen deficient. If no nitrogen shortage appears to be evident, delay adding fertilizer until the spring. Fall soil nitrate levels are usually high as is the potential for leaching. Late fall applications of fertilizer may accomplish little.

- Our recommendations total only 1.5 to 2.0 pounds nitrogen per 1000 square feet per year. We believe that this amount of applied nitrogen is sufficient to maintain quality turf if it is applied when it can do the most good. We currently have research underway to test this belief.

presses root growth. In some woody ornamentals, root growth stops when the spring flush of leaf growth is occurring. This takes place because of limitations of available energy. If available energy is being spent on rapid growth of leaves and stems, less energy is available to support growth and nutrient absorption in the roots.

To be specific, nitrate uptake will occur as long as the leaves are functioning photosynthetically and the environment surrounding the roots allows for metabolic activity. This explains why our findings show that nitrate concentrations in soil-water under turfgrasses are very low during the spring and early summer.

Nitrate levels begin to drop early in spring (March and April) when, under Rhode Island conditions, grass growth is slow. During that time of modest shoot growth, as the plants green up, photosynthetic activity increases producing sugars that are translocated to the roots, because demand for sugars by the shoots is limited. Our research has found that during warm days in the early winter-early spring period up to 25% of the sugars produced in the leaves are transported to the roots. Soil-water nitrate levels are usually decreasing during this period.

During the summer, soil-water nitrate levels increase rapidly and continue to do so during much of the fall. Certainly increasing nitrate levels are partly the results of increased fertilization and decomposition of soil organic matter during this period, but a substantial portion is due to the fact that late summer conditions are not conducive to root growth. Summer's stress from high soil temperatures, the depressive effects of weed growth, and roots being damaged by both insect and disease activity normally lead to a substantial loss of turfgrass root mass, even when a summer is conducive to maintaining good quality turf.

During this time, root absorption is not able to keep pace with nitrate production, making summer one of the periods with the highest potential for nitrate leaching. Fortunately, summer rainfall is normally not excessive and actual leaching is usually not a consistent problem.

During the late fall and early winter, turf root growth increases; often much of the root system is regenerated during this period. It has been estimated that as much as 80% of the root system of turfgrass is lost and regenerated

German study

Nitrate leaching into ground water shows low risk from golf course greens

A German study on nitrate leaching from a predominantly sand-based golf course green has found that, at reasonable levels of fertility, the actual amount of nitrate leaching is very low.

The Stuttgart study covered leaching from a green, constructed of 75% sand, 15% topsoil, and 10% peat moss, over a two year period. The year old, predominantly fine fescue green was subjected to three different nitrogen application loads (4, 8, 16 pounds per 1000 square feet per year) using four different nitrogen sources (Ureaform, IBDU, Corn meal, Ammonium sulfate) with the leachate collected 14 inches below the surface.

The annual collected leachate data in the first year for all the fertilizer sources produced the figures that are represented in the table, right. Only the data from the first year is shown, as the data from the second year are very similar to that of the first.

TGT's view: None of the fertilizer sources (Ureaform, a complex, synthetic organic; IBDU, a special polymer form of urea; Corn meal, a natural organic; or Ammonium sulfate, a fast-release mineral source) when applied at the reasonable four pound nitorgen rate and even the higher 8 pound nitrogen rate, produced nitrate leaching greater than 1% of the total nitrogen applied. Only when the nitorgen rate was pushed to the excessive rate of 16 pounds, did nitrate leach rates become excessive.

This study, although it was designed to produce statistically significant data, does not represent current nitrogen usage.

Most golf course superintendents do not exceed 3.5 to 4.0 pounds of nitrogen per 1000 square feet per year on sand based greens and tees, while many do not exceed 2.0 pounds on the slower leaching native soil greens and tees that make up the great majority of the golf course greens and tees in this country. Current nitrogen fertility practices probably do not contribute any more nitrate to ground water pollution than the 0.17% (4 pound average) shown in the table for applied nitrogen, and probably contribute considerably less. -CS each year. The rate at which this root regeneration occurs depends on the favorable cool and wet conditions of this period and the extent of the damage that had occurred during the summer months. Often many cool-season turfgrass species will not have fully functioning root systems until late November.

The graph on page 6 is a visual representation of the nitrate concentrations two feet under turf during the calendar year 1993. It illustrates the seasonal variations of that concentration in relation to days of the year and fertilizer applications made.

The cyclical nature of root growth is less of a problem on warm-season turfgrass species. These grasses grow best under warm temperatures and their root growth is not depressed during the summer. Because these species are less stressed during high temperatures, any root damage that may occur from insects or diseases is often regenerated more rapidly than their northern cousins. Consequently soil nitrate levels are usually low during the summer months on turf of warm-season species. However, as soils cool down during the fall and winter, these grasses often suffer a substantial loss in root mass, making the period from winter to early spring exhibit the highest potential for nitrate leaching.

How much nitrate can leach from turf?

After discussing the soil-turfgrass system with respect to nitrogen use and the opportunities for nitrate leaching, two questions arise: How much nitrogen can turfgrass plants actually utilize? And, how much nitrate can actually leach out of the turfgrass environment?

As to how much nitrogen can be utilized, the work of Dr. Dan Bowman at the University of California at Davis best answers this question. He found that when nitrate or ammonium was applied at the rate of one pound per thousand square feet (45 pounds per acre) to Kentucky bluegrass, 70% to 80% was removed in the first day and that virtually all was gone within 48 hours. The bluegrass plots that were used were modestly nitrogen deficient, but no more so than turf in the early spring. His work determined that of the nitrogen removed from the soil, 75% was absorbed by the turf and the remaining 25% was

Table

Collected leachate, first year

Pounds of nitrogen applied per 1000 square feet per year

Source	**4pounds/year (64oz.)**	**8pounds/year (128oz.)**	**16pounds/year (256oz.)**
Ureaform	0.23%* (0.15oz.)**	0.15%* (0.19oz.)**	0.69%* (1.77oz.)**
IBDU	0.15% (0.10oz.)	0.125% (0.16oz.)	5.00% (12.8oz.)
Corn Meal	0.15% (0.10oz.)	0.125% (0.16oz.)	11.2% (28.8oz.)
Amm. Sulfate	0.15% (0.10oz.)	0.70% (0.90oz.)	9.98% (25.6oz.)
Average	0.17% (0.11oz.)	0.28% (0.35oz.)	5.80% (17.2oz.)

* percent of total applied   ** equivalent amount

probably absorbed by microorganisms. This same rapid absorption of nitrogen was observed on perennial ryegrass, tall fescue, and creeping bentgrass stands.

In a companion study Dr. Bowman calculated that nitrogen deficient turfgrasses can absorb nitrogen at a rate of almost two pounds per 1000 square feet per 24 hours (90 pounds nitrogen per acre). It is little wonder that, when grass in vigorously growing in the spring, soil-water nitrate concentrations are reduced to very low levels. In fact, microbial mineralization of soil organic matter or slow-release fertilizers probably cannot satisfy the turfgrass needs at that time.

As to questions about how much nitrate can leach, our studies over ten years have found that total nitrogen leaching from applied fertilizer is never more than 15% of the total nitrogen applied. Also, we have found that nitrate leaching from naturally occurring organic matter in thin unfertilized turf may actually exceed that from healthy, dense well-fertilized turf. When total nitrogen applications are kept in the two to three pound range and organic nitrogen sources are used, annual leaching losses are more likely to be less than 5% of that applied or about five pounds per acre. By comparison, this loss is two to three times that which would leach from native forest and about 25% of that released by a single family septic system.

Bottom line

The bottom line appears to be: well-managed turf contributes very little nitrate to ground water and turf is one of the most environmentally sound ground covers available for both suburban and rural landscapes. ■

Lancaster County, PA, study

Farm nitrogen loading: a major cause of pollution

A three year study of nitrogen loads entering and leaving a 55 acre, organically managed farm in the Amish area of Lancaster County, PA, illustrates the large part that such agricultural practices can play in the nitrate contamination of ground water resources.

Before nutrient management practices were put into place, the annual total applied nitrogen from manure and commercial fertilizer averaged 480 pounds per acre (10.9 pounds per 1000 square feet) with nitrogen discharge rates that averaged 292 pounds per million gallons of ground water (36.5 parts per million). After applied nitrogen rates were reduced 33% to 320 pounds per acre (7.3 pounds per 1000 square feet), discharged nitrogen rates averaged 203 pounds per million gallons of ground water (25.4 parts per million), a 30% reduction.

The study estimated that 25% of the applied nitrogen was lost through volatilization as various gaseous forms of nitrogen and that 38% of the applied nitrogen was discharged into the ground water. The nitrogen losses averaged 100 pounds per acre per year (2.25 pounds per 1000 square feet per year) for both management practices due to volatilization and 152 pounds per acre per year (3.45 pounds per 1000 square feet per year) due to ground water loading. Including loss by surface runoff, less than 1%, the total nitrogen loss averaged 64% of applied nitrogen or 260 pounds per acre per year (5.91 pounds per 1000 square feet per year) out of a total average application of 400 pounds per acre per year (9.09 pounds per 1000 square feet per year).

TGT's view: The loss of applied nitrogen at this site into the air, surface water, and ground water was a staggering 64%, with 38% lost to ground water alone. If anyone had any questions concerning the relative contributions to nitrate pollution by agriculture and turfgrass management, this study and the German study, page 8, should answer them completely. In these two studies, on average, current "organically" oriented agriculture management practices were much more likely to contribute to nitrate pollution of ground water than current turfgrass management practices. Previously reported analysis of nitrate loading of ground water by septic systems, and Dr. Hull's identification of nitrate leaching from naturally occurring organic matter in the soil profile, clearly identify agriculture, septic systems, and organic matter as the three major contributors to nitrate loading of ground water resources. -CS