Getting to the Roots of Nitrogen-Use Efficiency

By Richard J. Hull

Nitrogen is the most abundant mineral element in turfgrass and is consequently the fertilizer nutrient most required for turf management. Because of its mobility in the soil and potential for causing environmental problems, nitrogen use in turf management has become a concern at community, state and even national levels. This concern has resulted in local regulations limiting the use of nitrogen fertilizers on golf courses, athletic fields and other large turf areas. National sustainable landscaping guidelines have been proposed that would limit or discourage the inclusion of turf in landscape designs.

This is unfortunate because the research comparing nitrogen losses from several rural and suburban land uses has shown woodlands and lawns to be the least contributors to nitrate pollution (Gold et al. 1990). By comparison, variously managed corn plantings lost 50 times more nitrogen through nitrate leaching into groundwater. Even when nitrate leaching from various landscape components was compared, several plantings leached more nitrate than turf (Hull & Amador 2008). Thus, the science simply does not support discriminating against turf as a landscape feature because of potential environmental harm from nitrate leaching.

The tendency of any vegetative land cover to discharge nitrogen into the environment (groundwater, surface water, atmosphere, etc.) is a function of its nitrogen-use efficiency. That is, the percentage of nitrogen available to a planting that's absorbed by the plants and retained against loss. In field crops, nitrogen-use efficiency is often expressed as the amount of harvested yield obtained per unit of nitrogen available to a crop. This latter definition is useful when food crops are being compared, but it makes little sense when turfgrasses are included in the comparison. For this reason, any evaluation of nitrogen-use efficiency by vegetation types should be based on nitrogen uptake by plants, assimilation into organic forms and retention against losses to the environment. We have developed these ideas more fully elsewhere (Hull and Liu, 2005).

Recently a team of Australian researchers reviewed the prospects for improving the nitrogen-use efficiency of crop plants based on their root characteristics and functions (Garnett et al., 2009). I thought it might be useful to compare some of their observations on cereal crops with the situation in a turfgrass sod. I will concentrate on comparing their analyses of cereal grasses with what is known about turfgrass nitrogen-use efficiency.

Root/soil interface

Even a casual comparison of cereal crops and turf identifies a number of obvious and significant differences. While both are grasses, cereals are annual grasses grown in rows while turf is composed of perennial grasses grown as a sod. These differences are enormously important when considering the stability of nitrogen in the plant/soil ecosystem. While both plants have fibrous roots, only the turfgrass sod maintains a functional root system throughout the year. This means that only during the growing season does the cereal plant community constitute a sink for available nitrogen in the soil solution. Even then, the roots of an annual grass are most vigorous and capable of absorbing mineral nutrients in the spring and early summer. But this capacity gradually declines as the plant matures and energy is diverted away from the roots and toward grain production. By comparison, both cool- and warm-season turfgrasses exhibit seasonal peaks in root activity. Only during extreme environmental conditions does root function totally stop.

Nitrogen fertilization rates of cereals are somewhat greater than those of turf, and cereals are generally fertilized heavily during the

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spring and early summer, when root activity is greatest, but rarely in late summer or fall. Cool-season turf is usually fertilized most heavily in the fall to promote recovery of the root system that was damaged during stress conditions of summer. Often, nitrogen is also applied at lower rates in early and late spring. Fertilization of warm-season turf is scheduled more like a cereal crop with greater emphasis on the spring and summer when root growth is most active. Even so, soil solution nitrate concentrations under a cereal crop average 84 parts per million nitrate-nitrogen (Garrett et al. 2009) while the solution of a turf soil averages about 2.5 ppm. This 34-fold greater nitrate concentration in cereal soils certainly makes them more vulnerable to nitrate leaching into groundwater. Because cereals recover only 33 percent of fertilizer nitrogen in harvested grain on average, nitrate leaching appears likely. In fact, the remaining 67 percent of applied nitrogen is lost either as surface runoff, nitrate leached to groundwater, volatilization as ammonia to the atmosphere, or as nitrogen gas and nitrous oxide due to bacterial denitrification of nitrate (Vitousek et al. 1997).

Because cereals recover only 33 percent of fertilizer nitrogen in harvested grain on average, nitrate leaching appears likely.

Turf, on the other hand, recovers the equivalent of 65 percent to more than 100 percent of fertilizer nitrogen in clippings, indicating that nitrogen uptake from the soil must be highly efficient. Several studies have shown that retaining clippings on the turf will allow a 35-percent to 50-percent reduction in nitrogen fertilizer with no reduction in turf quality.

Root morphology and density have been shown to influence nitrogen-use efficiency (Garnett et al. 2009). Root-length density, the length of root per volume of soil (inches/cubic inch), is positively correlated with nitrogen uptake by plant roots and negatively correlated with nitrate leaching. Thus, a larger fibrous root mass radiating throughout a greater depth of soil should increase the efficiency of ammonium absorption, and to a lesser extent, nitrate. Nitrate is highly mobile within the soil with 79 percent reaching root surfaces through mass flow and 20 percent by diffusion. Only about 1 percent of absorbed nitrate reaches the roots by interception as a result of root growth through the soil (Barber 1995).

Ammonium, however, is 10 to 100 times less mobile than nitrate since most of it is bound to soil colloids. Thus, a much higher percentage of ammonium would reach root surfaces through interception when elongating roots contact soil colloids. In soils where ammonium is a more significant component of available nitrogen, a greater root length density will markedly increase nitrogen-use efficiency.

Nitrogen transport in grass roots

The carrier proteins that transport nitrate and ammonium across root cell plasma membranes from the soil into living cells have been studied extensively in cereal grasses (barley, corn, oats) but much less so in turfgrass (Hull and Liu 2005). However, published research indicates nitrate and ammonium are absorbed by turfgrass roots every bit as efficiently as they are in cereal grasses, maybe even more efficiently. Within both grass types, there is considerable variability among species and often even more variation among cultivars within species. Thus, the potential exists for genetic improvement in nitrogen transport efficiency in both cereals and turf.

The regulation of nitrogen transport proteins has also been studied and it offers some explanation for differences in nitrogen-use efficiency between cereals and turfgrasses. The presence of ammonium in the soil solution can depress the root absorption of nitrate. Since ammonium is about 15 times more concentrated in soil water under cereals than it is under turf, it likely has a substantially greater inhibiting effect on nitrate uptake by cereal roots than it does on turfgrass roots. This easily explains the 34-fold greater nitrate concentration in the soil solution of cereal soils over that of turf soils and the accompanying much lower nitrate-use efficiency of cereal crops compared to turf.

Elevated nitrate concentrations in the soil solution tend to inhibit root growth, especially the development of lateral roots (Garnett et al. 2009). This reduces root-length density that further depresses nitrogen uptake, probably mostly ammonium uptake, and results in even greater soil water ammonium that further inhibits nitrate absorption. Other fac-

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tors also contribute to the lower nitrogen-use efficiency of cereals compared to turfgrasses. The perennial root systems of a grass sod contribute substantial amounts of organic matter throughout the soil profile as roots continuously die and are replaced. This organic matter supply encourages a complex microbial population that converts dead roots into organic soil colloids that in turn provide cation exchange sites that bind ammonium ions (NH4+). Being in equilibrium with ammonium ions in the soil solution, this colloid-bound reservoir of ammonium maintains a low but stable concentration of ammonium in the soil solution replacing that absorbed by roots or oxidized by microbes. The presence of both ionic nitrogen species in the root environment favors root absorption by helping to maintain ionic balance between root cells and soil solution (Garnett et al. 2009).

Colloidal organic matter also sequesters organic nitrogen within its chemical structure and serves as a slowly available stockpile of soil nitrogen. Soil organic matter accretion can accumulate carbon and nitrogen within the turf-soil ecosystem for about 45 years when it may exceed 4.5 percent of soil dry weight (Qian et al. 2003). From then on, the turnover of soil organic nitrogen is sufficient to support turf growth with little if any fertilizer nitrogen being added. Such a mature turfgrass sod will leach virtually no nitrate to groundwater unless it continues to be fertilized in excess of 25 pounds nitrogen per acre per year.

Accumulation of ammonium and/or amino acids (glutamine) within root cells will suppress nitrate and ammonium uptake by down-regulating the genes that encode for transport protein (Garnett et al. 2009). If this occurs, nitrate can accumulate within the soil solution and become vulnerable to leaching in the event of excess rain or irrigation. Excess nitrate in roots can and likely will be transported to the shoots, especially to the leaves. There, nitrate sends a signal to the roots, probably in the form of glutamine, to suppress further nitrate absorption and root growth.

Excess nitrogen in the leaves also diverts photosynthetic energy (sugars) toward greater shoot growth leaving less available for translocation to the roots, further depressing root growth. In cool-season turf, root deterioration can occur during periods of elevated soil temperatures. However, soil microbial activity will be stimulated under higher temperatures, increasing the oxidation of organic matter and the ultimate release of nitrate. Soil nitrate levels will increase and be subject to leaching if root absorption is inhibited. Warm-season turfgrasses are much less vulnerable to high temperature growth inhibition; in fact elevated temperatures stimulate them. All this results in a summer decline in nitrogen-use efficiency, especially in cool-season turf.

Because of their annual lifecycle, cereal grasses are unable to establish the complex association with soil microbes and organic matter metabolism that is characteristic of perennial grasses. Consequently, dramatic increases in their nitrogen-use efficiency may be difficult to achieve. At 33 percent nitrogen-use efficiency, there's room for improvement but Garnett et al. (2009) admit that a clear path to achieving improvement is not evident.

Thus, it appears that turfgrasses inherently pose less of a problem for nutrient loss than do most crop plantings. Grasses have been used for more than a century to stabilize soils and prevent nutrient losses. It seems only reasonable and research clearly confirms that no landscape component offers less threat to the environment than well-managed turf.

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