Part 1 of 2

See August's TurfGrass Trends for Part 2.

Recognizing the Nitrate Effect on Root Growth and Development

NO_3- presence in the leaves directs plant resources toward leaf and shoot growth at some expense of root expansion

By Richard J. Hull and John T. Bushoven

A vigorous and healthy root system is critical to maintaining high quality turf. Without sound roots, turfgrasses cannot acquire the mineral nutrients and water necessary to support good leaf growth and color and withstand the rigors of heavy use.

Recent evidence might cast the nitrate problem in a somewhat different light and may offer a few solutions.

In an earlier article, we discussed turf-management strategies that should insure optimum root growth and efficient resource utilization (Hull, 1996; visit turfgrasstrends.com and search "Hull" to see previous articles on fertility, nutrient availability and more). In that article, the negative impact of nitrate-nitrogen ($N0_3$-N) on root growth and its promotion of excess shoot growth were discussed (Fig. 1) along with some ideas of why this occurs. Because $N0_3$-N is the most abundant source of nitrogen available to roots in most soils, its potential for depressing root growth is all but inevitable and there is little the turf manager can do about it. At least, that was the impression you logically would get from that 1996 article. Here we are not refuting that conclusion, but we are suggesting that recent evidence might cast the nitrate problem in a somewhat different light and may even offer a few solutions.

For some time, we have been studying the efficiency of nitrogen utilization by turfgrasses at both the ecological level ($N0_3$- leaching & N budgets in turf) and the physiological level ($N0_3$- uptake efficiency and the partitioning of its assimilation within turfgrasses). These latter investigations led us to the realization that perennial ryegrass (*Lolium perenne L.*) and creeping bentgrass (*Agrostis stolonifera L.*), like many grasses, transport most of the $N0_3$- absorbed by their roots to the leaves where it is reduced to ammonia (NH_3) and assimilated into amino acids (Bushoven and Hull, 2001). These amino acids can then be transported from the leaves to all parts of the plant, including the roots, where they support cell division and growth.

Already we can see a problem because NO_3- in the leaves functions as a "signal molecule" that diverts sugars, made by photosynthesis, from transport to the roots to the synthesis of amino acids in the leaves.

As we shall see below, NO_3- metabolism requires much energy. If photosynthetic energy in the form of sugars is used to assimilate nitrogen, there will be less sugar available for transport to roots. Given the anatomy of a grass plant, the transport of sugars and amino acids from leaves must pass through the crown at the soil surface, where leaves are initiated and their growth supported, before they can reach the root tips where root growth occurs. In short, NO_3- present in the leaves directs plant resources toward leaf and shoot growth at some expense from root growth. That scenario alone explains how NO_3- favors turf leaf production and retards root growth.

There are other factors involved, however.

At this point, we need to clarify what we mean by NO_3- metabolism in leaves or roots. The process of NO_3- reduction and assimilation into amino acids is not a simple operation. It involves four chemical reactions catalyzed by four different enzymes. Nitrate reduction to NH_3 (NH_4+ is its ionic form) requires two reactions occurring in different compartments of leaf or root cells. In the cytosol (liquid phase of a cell's cytoplasm), NO_3- is initially reduced to nitrite (NO2-) by acquiring two electrons from the universal biochemical reducing agent: NADH. The enzyme catalyzing this reaction is Nitrate Reductase (NR).

The resulting NO2- is then transported into a plastid (chloroplasts in leaf cells, leucoplasts in roots) where it acquires six additional electrons from the reduced form of Ferredoxin (Fdred) and emerges as the fully reduced form of N: ammonium (NH_4+). The plastid enzyme Nitrite Reductase (NiR) catalyzes this reaction.

Ammonium is the only form of nitrogen that can be used by a plant to make amino acids and subsequently proteins, nucleic acids and all other nitrogen-containing compounds. These two reactions constitute NO_3- reduction.

The assimilation of NH_4+ into an organic molecule (amino acid) also generally occurs via two reactions. The first reaction involves the binding of NH_4+ to the #5 carbon atom of the 5-carbon amino acid, glutamic acid (ionic form is glutamate), to form the amide-containing amino acid: glutamine.

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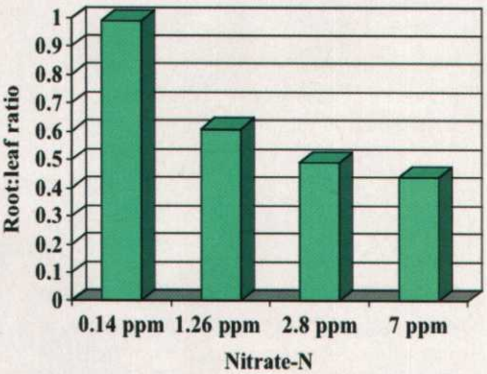
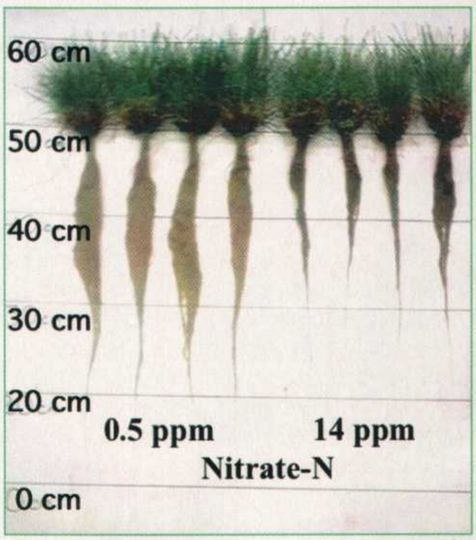
Glutamine Synthetase (GS) is the enzyme that catalyses this pivotal reaction by which inorganic nitrogen (NH_4+) enters the world of organic biochemistry. Glutamine is an amide amino acid that functions as a universal nitrogen donor for the synthesis of many N-compounds in plants,

Continued on page 66

Root Growth and Nitrate Availability

As nitrate availability increases, exceeding root capacity for nitrate reduction, root growth is inhibited.





Continued from page 65

animals and micro-organisms. However, to complete this sequence, we need to regenerate glutamate so it will be available to accept another NH_4+ and keep the process going. This process occurs when glutamine donates its amide-N to the No. 2 carbon of a-ketoglutarate (derived from mitochondrial respiration) producing two glutamate molecules.

Glutamate Synthase (GOGAT) is the enzyme that catalyzes this reaction and it also is confined to plastids. Don't ask how you abbreviate Glutamine Synthase to GOGAT; it is actually the abbreviation of a longer more technical name of the enzyme. In this reaction, a-ketoglutarate must first be reduced before it can accept an amide-N and that requires two Fdred molecules as electron donors. One of these glutamates can serve as an NH_4+ acceptor while the other can be used to synthesize other amino acids or become directly incorporated into proteins.

This reaction sequence requires a total of 8 Fdreds, and 2 NADHs (about 5 NADHs) in addition to an ATP for each NO_3- metabolized. That represents a lot of energy, almost equivalent to that required for the photosynthetic fixation of two carbon dioxide (CO_2) molecules. In fact, since most of these reactions occur in chloroplasts (at least in leaf cells) they draw upon the very same photoenergy used to assimilate CO_2. Therefore, NO_3- metabolism can be viewed as a type of photosynthesis. In this analysis, we haven't even considered the energy required to make the 5-carbon compound (a-ketoglutarate) required for the last reaction of the NO_3-metabolism sequence.

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