PART ONE
OF TWO PARTS

Nutrient Interactions In Turf Management

By Richard J. Hull & Haibo Liu

Over the past several years, we've discussed the roles of essential mineral nutrients in turfgrasses and their impacts on turf management in this journal. Rarely did we consider the interactions among nutrients and how such interactions influence turf quality and the appropriate nutrient management of turf.

While certainly not ignored by turf researchers, this subject has rarely been the primary focus of nutritional investigations. As a result, there appears to have emerged relatively few overarching principles governing the composition of turf fertilizers, especially the optimal balance between macro and micronutrients.

A compartmental model

Contributing to the complexity of nutrient balance in turf is the compartmental nature of the turf-soil ecosystem. For simplicity, we can visualize this system as consisting of three principal interacting compartments: soil (especially soil solution), root cell walls (apoplast) and interconnected protoplasts of root cells (symplast).

Nutrient absorption by turfgrass roots involves transfer of nutrient ions through these compartments such that the composition of nutrients within root cells will be very different from that of the soil solution. Differences will include the ratios of nutrients to one another and their concentrations. For example, there may be more calcium (Ca) than potassium (K) in the soil solution but substantially more K than Ca within the cytoplasm of root cells. Also, K within root cells may be 10 to 100 times more concentrated than it is in the soil solution.

There's obviously a good deal of quantitative and qualitative selectivity in the transport of individual nutrients through the compartments of a turf-soil ecosystem.

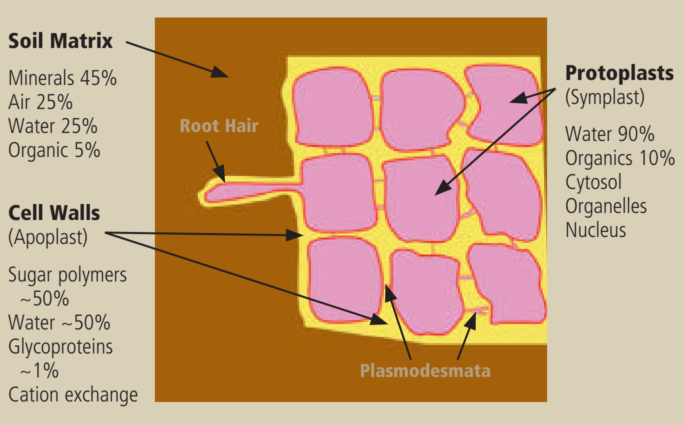
The environments within the three compartments comprising the turf-soil system also differ substantially. The nutrient cation (positively charged ion) composition of the soil solution is controlled by their relative ionic binding strength with the cation exchange sites on colloidal clays and organic gels. The comparative binding strength of common soil cations, in order of decreasing strength, is as follows (Brady and Weil 1999):

$$Al^{3+} > Ca^{2+} > Mg^{2+} > K^{+} = NH_4^{+} > Na^{+}$$

In most soils, cations of each nutrient element are bonded to negative charges on mineral and organic colloids. These ionic bonds are reversible and tend to maintain the free cation concentration in the soil water within a reasonably narrow range. However, these buffered concentrations can be disturbed dramatically following applications of a soluble fertilizer or during periods of drought. Nutrient anions are bonded only weakly to colloids but are often in equilibrium with almost insoluble salt crystals or gels that help maintain their ionic concentration in soil water.

Highly soluble anions are mostly in the soil solution and are free to leach to the subsoil and ultimately into the water table when water percolates through the soil pro-

Model of Root-Soil System Compartments



file. Root cells are enclosed within cellulose-based cell walls. The carbohydrate polymers that comprise these walls are highly hydrated and constitute an aqueous phase from which root cell protoplasts acquire their water and mineral nutrients. Since roots grow in the soil, their surface cells are bathed in soil water. Any nutrient ions available to a root must find their way from soil water into this cell wall space before they can be absorbed within living root cells.

The environment of the cell wall space is often quite different from that of the surrounding soil. Within the apoplast, much of the water is bonded to the polymers that comprise the cell walls but free water is reasonably abundant as well.

Some of these carbohydrate polymers (pectins) contain sugar-acid units that, at a pH above 4.5, will release a H^+ from their carboxyl group leaving a negative charge on the polymer. These negative charges will attract and bind with cations much as cation exchange sites do in the soil. Because of these cation exchange sites, water in the cell walls will contain a greater concentration of nutrient cations than will be present in the soil solution and likely a somewhat lesser nutrient anion concentration but one still greater than that of soil water.

Cell wall spaces will have an elevated H^+ concentration because H^+s are also attracted from the soil water and in addition, are pumped out of the protoplasts into the apoplast during normal cell functions.

For the reasons cited above, the apoplast from which nutrient ions are actually transported into root cell protoplasts is likely to be more acidic and have a greater nutrient concentration than the soil water.

The protoplasts of root cells are interconnected by tiny protoplasmic tubes called plasmodesmata and constitute a network of living protoplasts that can develop independently yet exchange materials and information among themselves and throughout the plant. This living protoplasmic network is called the symplast. Each cell's protoplast is enclosed within a plasma membrane that separates the living part of a cell from its external nonliving cell wall (apoplast). To enter into a protoplast, all water and nutrient ions must cross a plasma membrane that is selectively permeable, allowing some ions to cross while excluding others. Thus, the protoplast compartments of a root can have a nutrient composition very different from that of the soil solution and its surrounding apoplast.

It is within the plant that nutrient balance is most critical since it is here that nutrients perform their metabolic functions. Once absorbed by root cells, nutrients are distributed throughout stems and leaves via xylem elements of the vascular system. Transpiration of water from leaves provides the driving force for upward movement of water and nutrient ions within xylem elements. Some nutrient ions can exit the leaves via sieve elements of the phloem and circulate throughout the plant. Such nutrients are likely to be sufficient for growth of meristems (growing points) but may become deficient in leaves. Others have limited phloem mobility and may become deficient in meristems while remaining adequate in leaves. These resulting nutrient imbalances within the plant can cause problems that will be discussed later, but often may be addressed through foliar fertilization.

Plant nutrients will interact with each other differently within each of these three compartments making nutrient availability to, uptake by and distribution within plants a highly complex phenomenon.

We will explore these nutrient interactions in the soil in the next article in this series.

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