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BACK-TO-BASICS

Understanding Turfgrass Roots — Part 1

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Part 1 of this Back to Basics series on turfgrass roots details system development, function and dependence on water uptake. Part 2 in next month's issue will cover nutrients, hormonal balance and proper cultivation techniques

It might be safe to say that the secret to effective turfgrass management is developing the art of growing and maintaining healthy roots. Although roots are not generally visible, they are so essential to the well-being of turf that the turf manager who neglects them does so at considerable peril. This is the second of a three part series on turfgrass morphology, function, physiology and management. The first explored the turfgrass crown (Hull, 2000) and a future article will discuss turfgrass leaves.

Water uptake by roots is controlled by two conditions: the contact of soil water with root cell membranes and the number and permeability of aquaporins.

Development and function

In the initial article, I noted that the young turfgrass plant has two root systems: a primary system that originates from the radical (seed root) after it emerges from the germinating seed and an adventitious system initiated at the first stem node that develops in the coleoptile (shoot emerging from the seed) after its tip reaches the soil surface and experiences light (Fig. 1).

This initial node eventually develops into the crown of the grass plant (Hull, 2000). During the seedling year, both root systems are functional but thereafter the adventitious roots comprise the entire functional root system.

Adventitious roots can also emerge at the nodes of horizontal stems (rhizomes and stolons) and these too can become part of the plant's permanent root system. Nodes of a tiller just above the soil can, under favorable conditions, produce short prop roots that may penetrate the soil but their contribution to turfgrass plants is questionable.

The longevity of roots in perennial grasses is a matter of some debate. Turgeon (1999) describes Kentucky bluegrass as a perennial rooting grass while some bentgrasses, perennial ryegrass, bermudagrass and rough bluegrass experience yearly root replacement and are considered annual rooting grasses. However, in her classical studies of the annual growth cycle of perennial cool-season grasses, Stuckey (1941) concluded that perennial grasses renew their root systems each year. My own experience with cool-season grasses would lead me to agree with Stuckey but clearly under favorable conditions, roots that do survive the rigors of summer heat,

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may resume growth in the fall and contribute to the newly developing root system that over-winters and supports grass growth in the spring.

Root growth

Even if turfgrass roots are capable of living for more than a single year, the practical reality is that few do. Most root growth of cool-season grasses occurs during the mid to late fall with the greatest flush recorded during the early to mid spring (Turgeon, 1999). Even during the winter, if the soil is not frozen, roots continue to grow and can acquire much of their photosynthetic energy from shoots during the coldest time of the year.

When the heat of summer raises soil temperatures to above 75° F, root growth is depressed and can stop altogether. The reasons for this summer decline in root growth of cool-season grasses is complicated and not completely understood but it probably results from high temperature induced inefficiency of photosynthesis caused by elevated rates of leaf photorespiration (Hull 1999b).

In short, when soil temperatures rise, turfgrass roots experience their greatest demand for carbohydrates, but heat induced photorespiration in leaves reduces photosynthetic production and less energy is transported to roots. As a result, roots consume most of their carbohydrates and become starved (Huang, 2000).

Root decline slows water uptake resulting in less transpirational cooling of leaves and this reduces photosynthetic efficiency even further. This bad situation is made even worse by heat stimulated soil-born diseases and root feeding by soil insects and nematodes. As a result, most cool-season turfgrasses will have lost more than 75% of their roots by late summer, necessitating the regeneration of a new root system during the cooler times of the year.

By comparison, warm-season turfgrasses produce most of their roots during late spring and summer (Turgeon, 1999). Because such grasses do not experience heat-induced photorespiration, their photosynthetic rates actually increase during the heat of summer supplying adequate carbohydrate energy to support root growth. Warm-season grasses suffer a rapid decline in photosynthesis during the onset of cool temperatures and this denies roots the means for continued growth.

While studies indicate that many roots can survive the winter and even manage some growth, this is always much less than will be observed in cool-season grasses. Dr. James Beard and his colleagues (Sifers et al., 1985) reported a spring phenomenon in warm-season turfgrasses that they called spring root decline. This is most evident during years when soil warming occurs rapidly, stimulating root metabolism and growth before the shoots have regenerated sufficiently to supply the photosynthetic energy necessary to support this root activity.

The result can be a rapid death of the root system which must then be regenerated before normal grass growth can proceed. This rapid root decline delays spring rejuvenation of the turf and can make it vulnerable to drought and slows recovery from mechanical injury. Spring root decline does not occur every year but is frequent enough to give southern turf managers reason for concern during the early spring.

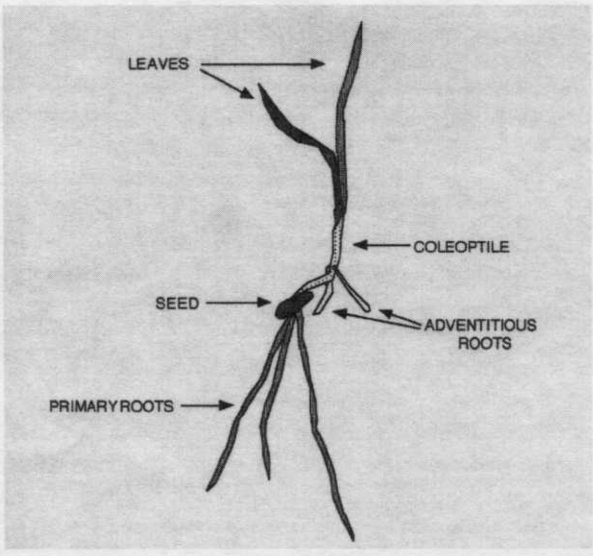

Fig. 1. Primary and adventitious roots developing from a turfgrass seedling.

It is evident that root health is essential for optimum turfgrass performance, but to understand how roots conduct their vital functions, it is necessary to appreciate the physiology of root systems and the structures that assist in their function. This article will concentrate on the structure and function of turfgrass roots and conclude with some ideas of how management strategies can maximize root survival and performance.

Root structure and function

Turfgrass roots are the organs through which turf receives most of its water and mineral nutrients and by which it is anchored in the soil. This latter function is especially critical for athletic field turf and any grass subjected to physical stress or wear. Also, as an integral part of a turfgrass plant, roots contribute to the hormonal balance within the plant by which grasses can respond to environmental and management variables such as water uptake.

Water uptake: Among the most important functions of plant roots is the acquisition of soil water. Without water there is no life and this is as true for turfgrasses as for any living organism. Seed germination is first noted by the emergence of a primary root emphasizing the importance of soil contact and a water supply for further plant growth. The ability of roots to acquire water depends on their surface area (contact with water), their growth rate (exploration for water sources) and their maintenance of a water potential more negative than that of the soil (energy powering water uptake). We have discussed the physiology of water uptake by roots in an earlier article in this series (Hull, 1999a); here more attention will be devoted to structural considerations.

A grass root consist of a cylinder that grows from a region of cell division and elongation near the tip and acquires water and nutrients primarily throughout a region of absorption often recognizable by numerous root hairs (Fig. 2). The meristematic (dividing) cells of the root tip are protected by a root cap as the elongating cells push the tip through the soil. Cells of the root cap also are formed by the meristem but they excrete mucilage and are themselves dislodged from the root as they lubricate the passage of the tip past soil particles. This process occurs more easily in soils that are moist, friable and enriched with organic colloids. Hard, dense, dry soils restrict root extension.

Water absorption occurs when soil water crosses the plasma membrane of root cells. For this to happen, soil water must make contact with the outer membrane of root cells and its activity (mostly concentration) must be greater than water within the cells.

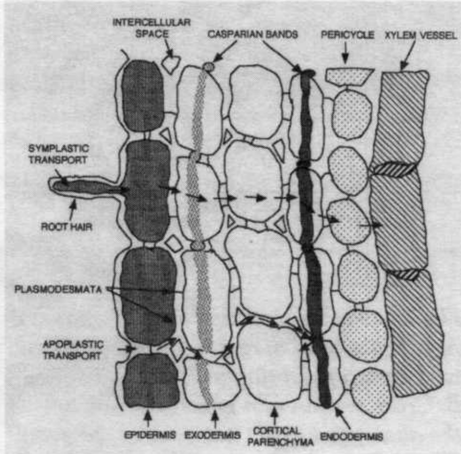

Fig. 3 Diagram of root (longitudinal view) showing apoplastic and symplastic transport routes.

Because cell membranes are largely composed of lipids, there must also be pores in the membranes through which water can pass from the soil into the root cells. These pores or aquaporins are protein channels that permit water molecules to pass single file across the membranes (Maurel, 1997). Water moves from the soil into the root cells as long as there is more free water in the soil than there is within the cells.

Thus, it is important for root cells to maintain a high solute (mineral ions, sugars, organic acids, etc.) concentration that will dilute the cell water making it less free than water in the soil. Energy is required to accumulate and retain solutes, as we will see in the next section, and this energy ultimately comes from photosynthesis.

Water uptake by roots is controlled by two conditions: the contact of soil water with root cell membranes and the number and permeability of aquaporins. At this point, it is good to remember that plant cells are enclosed within a cell wall so the plasma membrane never directly contacts the soil. Water moves from the soil into the cell walls and there makes contact with the cell membrane.

Cell walls are composed of long polymers of carbohydrates (sugars); some are well ordered and reasonably rigid (cellulose) while others are more random and gel-like (hemicellulose and pectin). All these sugar molecules contain several hydroxide (-OH) groups that have a high affinity for water. As a result, the cell wall is highly hydrated and allows the free passage of water so long as there is a water potential gradient moving it along.

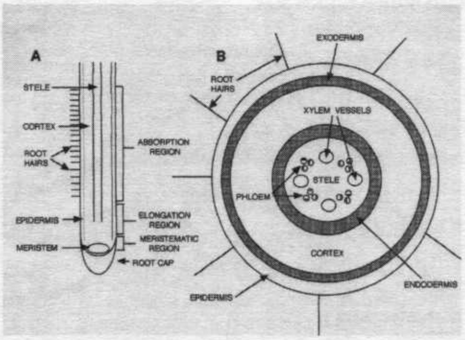

Fig. 2. ***Grass root structure.***
A. Longitudinal diagram through a young root showing developmental regions.
B. Cross section of a grass root through the absorption (root hair) region showing tissue types.

Because every cell of the root is enclosed in its cell wall, plant tissues, including roots, consist of two continuous phases: the nonliving cell wall phase and the living protoplasts that are enclosed within their plasma membrane. The protoplasts are not isolated islands of living stuff imbedded randomly in a matrix of cell walls but rather are also interconnected by thin proplasmic tubes (plasmodesmata) that cross the cell walls between adjacent cells.

Thus the living protoplasts of plant tissues comprise an interconnected protoplasmic continuum (the symplasm) imbedded in a nonliving cell wall continuum (the apoplasm). This structural concept of plant tissues is important because it defines two transport routes that water and nutrient ions can take as they move throughout the plant body.

Therefore, water being absorbed by a root first enters the cell walls of epidermal cells that comprise the outer layer of a root. This water can move through the apoplast of epidermal and cortical cells around the living protoplasts and never actually enter a cell as it is drawn through the root (Fig. 3). If water and soluble mineral ions could pass unobstructed throughout the plant in the apoplastic phase, there would be no way for a plant to regulate what passes from the soil to the shoots.

To prevent this uncontrolled movement, some root cells insert waxy materials (suberin) into their cell walls. These waxy walls block the free movement of water and solutes within the apoplasm forcing them to cross a protoplasmic plasma membrane and continue their movement within the symplasm. Suberized cell walls are located at two regions of a root: the hypodermis and endodermis (Schreiber et al. 1999).

Both of these barriers to unobstructed apoplastic transport are located in the root cortex (Fig. 2). The hypodermis is a layer of cells just inside the epidermis while the endodermis is the inner-most cell layer of the cortex that borders the stele: the vascular core of a root. Normally the endodermis differentiates first forming a suberized band within its radial walls: a Casparian strip.

Fig. 4 A dispersed fibrous root system of Kentucky bluegrass. From such scanned images, root length, diameter and surface area can be determined and partitioned into several size classes.

This may be followed by a similar suberization of hypodermal walls forming an exodermis that is often induced by some stress condition. As these cells differentiate further, their entire cell walls can become suberized and apoplastic transport of water and ions across the root is effectively blocked.

Water normally can enter the symplasm via aquaporins that span the plasma membranes. Once within the symplasm, the apoplastic barriers pose no obstruction to radial transport of water and it can enter the vascular cells of the stele (vessels) and be drawn through the length of the root, to the stem and into the leaves following the water potential gradient created by transpirational water loss from the leaves. Because the passage of water through aquaporins can be controlled by root cells, the plant can regulate the amount of water passing through it (Maurel, 1997).

Most of the observations described in the sidebar "Root system anatomy" (see below) have been made in roots of corn and small grains and it is difficult to say how directly they apply to closely mowed perennial turfgrasses.

It is likely that xylem maturation may be delayed or even inhibited because of the reduced leaf surface maintained and the lower supply of photosynthetic sugars transported to roots. What likely does apply to turfgrass roots is the importance of fine branch roots in both water and nutrient acquisition. Also, the greater drought tolerance of tall fescue and some cultivars of other grasses that grow more of their roots at greater soil depths (Sheffer et al., 1987) may not only be a function of having access to more water but also maturing more large xylem vessels that can deliver water more efficiently to the shoots. Much useful research on turfgrass root anatomy and maturation remains to be done.

ROOT SYSTEM FUNCTIONS

Consider a root system in its entirety how its functions are organized. The adventitious roots emerging from the crown or nodes of rhizomes and stolons elongate and grow mostly in a downward direction. These nodal roots become the framework roots that pretty much shape the general architecture of a root system.

From these roots, numerous fine lateral or branch roots emerge a few inches or more behind the root tip and often do not grow to more than an inch in length (McCully, 1999). Branch roots may themselves branch but this varies with grass species and soil conditions.

Many lateral roots and their branches are determinate, meaning that their apical meristem matures and stops producing new cells, allowing the root to mature right to its tip where the root cap is lost and root hairs may be found. These fine roots can be long-lived and are generally considered the most important component of the root system for water and nutrient acquisition. These roots have the greatest surface area and make the greatest contact with the soil and its moisture.

The fine absorptive roots have all the cell types normally comprising a root but their cortex may consist of little more than an exodermis and endodermis and their stele may contain only a few vessels (3 to 4), an equal number of small phloem clusters and several undifferentiated parenchyma cells.

Unlike the framework roots that lose their epidermis and some cortical cells as they mature beyond the absorptive region and develop a true rhizosphere, fine roots retain a functioning epidermis with long-lived root hairs and an intact cortex. Such roots do secrete high concentrations of organic acids and chelating compounds that enhance the availability of soil phosphorus and iron.

Recent evidence has established that the largest vessel elements mature several inches from the root tip of framework roots and not within the root hair zone as had been thought (McCully, 1999). These large, late metaxylem vessels may be present in the young regions of a root but do not mature and become functional until the region of lateral root production is reached.

These large vessels develop as functional conduits for water and nutrients closer to the tip in branch roots where most absorption occurs. In the younger regions of a root, water conduction occurs through much smaller protoxylem and early metaxylem vessels.

Even these are immature and largely nonconducting in those root tip regions that have been most studied in experimentation. In corn, the maturation of large metaxylem vessels increases the water conducting capacity 1800 times. Because water moves out of such mature roots so rapidly, their relative water content decreases as does their water potential.

Editors' note: Part 2 will be published in the November issue of Turfgrass Trends.

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