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Managing Turf for Maximum Root Growth:

Are You Making Your Job More Difficult by Not Getting to the 'Roots' of Many Turf Management Problems?

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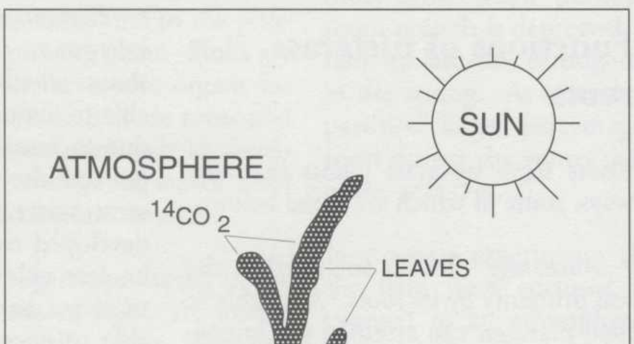
Each week throughout the growing season, the Turfgrass Diagnostic Clinic at the University of Rhode Island, directed by Professor Noel Jackson, receives dozens of turf samples from all over the United States. While most of these samples evidence problems of disease, there are many afflicted with either nematodes or insects, and some show symptoms of environmental stress disorders. Most of these samples have one characteristic in common: a badly damaged root system. It almost appears that turf does not exhibit symptoms, which a turf manager can recognize as a problem, until its roots are compromised. The putrid condition of, and foul odors often emanating from, the roots of afflicted turf provide ample evidence that healthy turf depends upon vigorous roots.



Figures 1 & 2 provided courtesty of Dr. Richard J. Hull.

Figure 1. Source - sink relationships among organs of a turfgrass plant being exposed to carbon-14 labeled CO_2.

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Why are roots so important to turf quality? The answer probably lies in the fact that turf is composed of a population of grass plants that are maintained at pretty close to their limit of endurance. This is especially true of putting green turf which is cut at a height of less than a quarter inch and subjected to heavy foot traffic. Also, fairway, athletic field and lawn turf is managed to produce continuous growth even when environmental signals are telling the grass to shut down and go dormant. Continuous growth is essential to repair injury caused by play, insect feeding or disease. Because turfgrasses are prevented from going through their normal cycle of vegetative and reproductive growth, followed by rest, during periods of environmental stress, they must maintain a constant supply of photosynthetic energy, from their leaves, as well as mineral nutrients and water, from their roots. If either one of these basic supply functions fails, the grass quickly goes into decline and exhibits injury symptoms.

Functions of turfgrass roots

Roots serve turfgrass plants in many ways, some of which are listed below:

• *Anchorage* - Turf is anchored to the soil primarily by its roots. Any athletic field manager can attest to the importance of a strong root system in preventing turf damage during vigorous play; the best looking turf will be little more than clumps of grass in a sea of mud, midway through a football season, unless that turf is endowed with a well established, deep root system.

• *Absorption of water and nutrients* - Virtually all mineral nutrients and water enter turfgrass plants through their roots. To utilize fully the available soil resources, a turf must have an extensive network of roots that ramify throughout the greatest possible volume of soil. The more effectively turf roots can mine the soil for water and nutrients, the less these resources must be supplied by the turf manager. An extensive system of roots also offers the greatest insurance that mobile plant nutrients, such as nitrate, will not leach through the root zone and contaminate ground water.

• *Stress tolerance* - During times of environmental stress, such as periods of drought or excessively high temperatures, a deep root system is the greatest protection turf can have. Well rooted turf will respond more quickly to fertilization and the other management practices that are intended to help turf recover after a damaging summer season. Turf, when well anchored by its roots, is also less likely to suffer injury during the freeze and thaw cycles of winter. Such turf will better tolerate the attack of root feeding grubs or other animals that can easily destroy turf with a poorly developed and weak root system.

• *Hormonal signals* - Roots produce hormones which inform the grass shoots whether soil conditions are suitable to support vigorous growth or if, due to imminent stressful conditions, the turf should reduce growth to conserve water and nutrients. A poorly developed root system, however, will be less able to send such hormonal messages and, as a result, will be less able to coordinate grass growth with environmental conditions.

• *Soil organic matter* - The production of an extensive root system introduces raw organic matter throughout the upper foot of soil. Over the years, this annual recycling of fine roots results in an increase in residual soil organic matter which contributes to greater water holding capacity, increased cation exchange capacity, better aeration and generally superior soil physical structure. All these changes make the soil a more suitable medium for root growth and improve the condition and resiliency of turf.

Because roots provide so many important functions for healthy grass growth, as well as contributing in a major way to optimum turf performance, it is wise for the turf manager to consider the impact of turf management practices on the condition of roots. That sounds reasonable, but exactly how do you manage turf to optimize root condition and function? To answer this question, you need to understand how turfgrass plants produce and maintain roots.

Energy partitioning in turfgrass plants

Because roots grow within the soil, they are totally dependent on the photosynthetic activity of the shoots for their carbon and energy (Fig. 1). Plant physiologists have established a concept of sources and sinks to describe the partitioning of photosynthetic products (photosynthate) within a plant. Photosynthesis, the process in which atmospheric carbon dioxide is fixed into sugars, occurs in green organs called **sources**. Leaves are clearly sources, but in grasses, stems and various structures comprising the inflorescence, such as bracts and awns, are also green and can thus contribute to the photosynthetic output of the growing plant. **Sinks** are organs which depend upon the source organs for their carbon and energy. These include roots and underground stems (rhizomes), as well as developing fruits and seeds, and even young leaves, until they are fully expanded and become sources.

Photosynthetic products (sugars), produced in the source leaves during periods of light, are loaded into specialized transport cells (sieve elements) where they are carried as a stream to organs where they are unloaded from sieve tubes and are either used for growth or placed in storage (sinks). This process of sugar transport from sources to sinks is called **photosynthate translocation** and the general phenomenon of carbon distribution within a plant is known as **photosynthate** (sugar) **partitioning**. The general partitioning pattern in plants involves translocation from sources to sinks. This article focuses mostly on photosynthate partitioning between leaves and roots.

For roots to grow and invade a large volume of soil, they must receive sugars from the source leaves in quantities sufficient to support the production of new root cells, provide the energy necessary for nutrient uptake, and supply the resources needed to maintain existing roots in good condition. This would be no problem if roots were the only sinks calling for photosynthate from the source leaves; however, since shoot growth (developing leaves and stems) also depends on the same sources for its carbon and energy needs, this is not the case. Furthermore, because shoot sinks are often much closer to the source leaves than are the roots, they usually enjoy a higher priority in photosynthate partitioning. The roots often receive output from the source leaves only when the total photosynthetic production is sufficient to meet the demands of all sink organs.

Based on the picture outlined above, it is not difficult to anticipate when turfgrass roots might come up short in this competition for source output. When shoot growth is stimulated, most of the photosynthetic product is partitioned to shoot sinks, leaving roots with whatever is left over. This is often not enough to support vigorous root growth; therefore, a sharp decline in root activity normally accompanies rapid shoot growth. When is root production favored in turfgrasses? This depends on many factors, but, as a general rule, roots grow when photosynthesis is active, but shoot growth is depressed. This occurs during the mid- to late-fall, throughout the winter, and early in the spring. As a result, cool-season turfgrasses partition larger percentages of photosynthate to roots during the winter than during any other time of the year (Fig. 2).

In a certain experiment, circles of turf growing in the field were enclosed in a glass bell-jar and exposed to an atmosphere containing carbon-14 labeled CO_2. Carbon-14 is radioactive; the plant cannot distinguish it from ordinary CO_2, but it can be detected using a Geiger counter. When the $^{14}CO_2$ is fixed photosynthetically into sugars, it is partitioned within the plant according to the source-sink relationships that prevail at the time. When turf was exposed to $^{14}CO_2$ at different times of the year, we were able to determine what portion of net photosynthetic product was partitioned to roots and how much was retained in the shoots (Fig. 2). During the winter, it is clear that roots constitute a major sink for photosynthetic product; this declines during the spring and summer, and reaches a low during early fall.

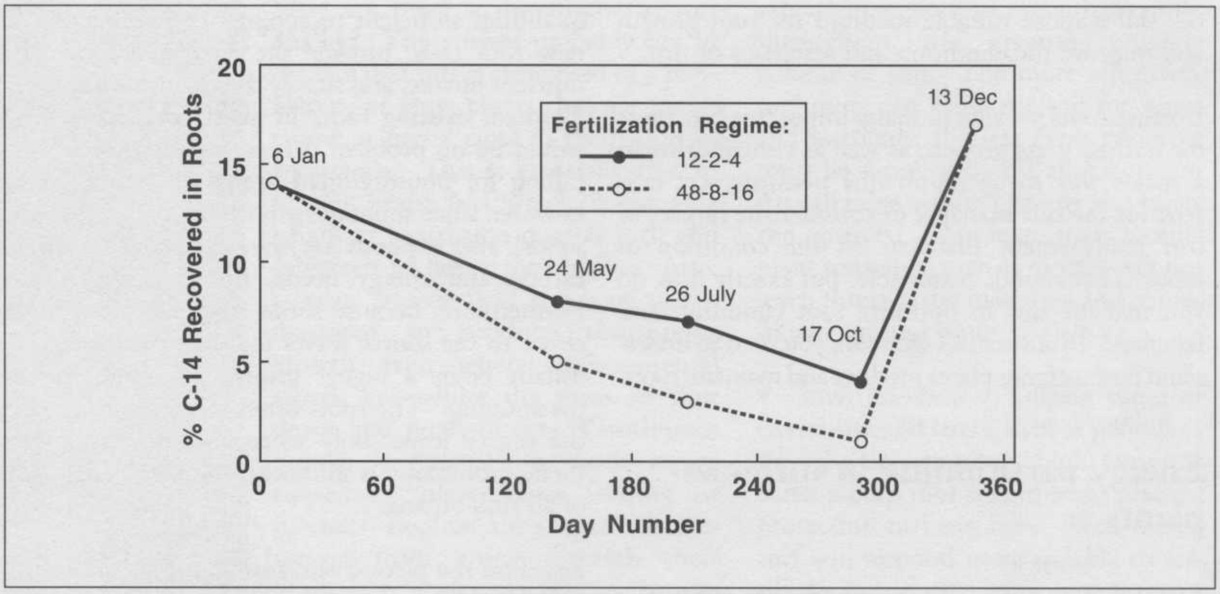

Figure 2. Percentage of ^{14}C-photosynthate recovered in roots of Kentucky bluegrass turf 48 hours after exposure to $^{14}CO_2$ at various times of the year.

It should be noted that this research was conducted in coastal Rhode Island, where winters are mostly free of snow cover and where winter days often reach above freezing temperatures. In colder climates, where the soil remains frozen throughout much of the winter, the sink activity of turfgrass roots probably does not occur to the extent shown in Fig. 2. However, throughout the winter, most cool-season turfgrasses retain substantial amounts of green leaf tissue that becomes photosynthetically active whenever days are bright and the temperature approaches 40° F. At that time, shoot sinks are inactive and roots, which will grow whenever the soil is not frozen, become the major sinks for photosynthate.

The failure of roots to benefit from reduced shoot growth during mid-summer deserves some explanation. The general rule, that whenever grass does not need mowing, roots are probably growing, frequently does not apply during the heat of summer. When mid-day temperatures exceed 85° F, cool-season turfgrasses experience high rates of photorespiration which lowers the net photosynthetic rate. At high temperatures, photorespiration increases much more rapidly than photosynthesis, resulting in reduced production of translocatable sugars. This low photosynthetic output is unable to meet the needs of shoot sinks; their growth is reduced, hence less mowing. Under such conditions, roots receive almost nothing, and, as a result, their growth becomes even more depressed. This does not help the turfgrass plants, since, under these conditions, their roots are unable to seek out water and nutrients, thus making them especially vulnerable to drought injury. This is the primary reason cool-season turfgrasses often experience a summer decline even when moisture and nutrient levels are adequate.

When cool temperatures return in the fall, daytime respiration rates return to normal and net photosynthetic production is able to support growth. Initially, shoots constitute the strongest sinks and leaf growth recovers from its summer decline. When sufficient leaf surface (source tissue) has been restored, photosynthetic output is capable of supplying sugars to the roots. By this time, the turf root system is probably less than a quarter of what it was in the spring. Reduced growth, insect feeding and normal turnover have taken a heavy toll of the roots during the summer. Even though the turf may appear healthy and require normal mowing during September and October, it is probably operating on a badly depleted root system. Depending on the early fall conditions, it will be mid- to late-November before a reasonably adequate root system has been regenerated. As cold temperatures depress sink activity in the shoots, roots will receive an increasingly larger share of source output and will respond by growing rapidly.

Factors governing root growth in turf

While the scenario outlined above provides a general idea of annual root growth in cool-season turfgrasses, this pattern can be influenced by environmental conditions and management practices.

• *Mowing height* - The root-shoot ratio of turf is obviously influenced by mowing height. The closer turf is mowed, the less source tissue is retained to support sink activity, including root maintenance and growth. While the root-shoot ratio declines throughout the summer, even under the best of conditions, a closely mowed turf will have fewer photosynthetic resources available to support root growth and a less well developed root system will be the result.

• *Light intensity* - Light availability will influence carbon partitioning between roots and shoots. Since photosynthesis is powered by light energy, source strength depends directly on the intensity of light. Because of leaf canopy shading, the net photosynthesis of turf normally increases as light increases, even when light levels exceed those which would saturate photosynthesis in a single leaf. Therefore, turf growing in full sun will have more photosynthetic energy available to support root growth than turf growing in partial shade. Turf growing under the shade of trees or on the north side of a building generally has a weaker root system than turf growing in full sun. Of course, shade grown turf may experience less drought stress, cooler temperatures and less insect predation of its roots so, by summer's end, it may actually have more root mass than if it had been growing in full sun.

• *Nitrogen supply* - When turf has been growing on inadequate nitrogen and nitrogen suddenly becomes available, root growth can be stimulated. However, when chronically over-abundant, nitrogen depresses root growth relative to shoot growth: the root-shoot ratio decreases. Turf roots are often exposed to excess soil nitrate following fertilizer applications or during the summer and fall when mineralization of soil organic matter releases more nitrate than can be absorbed by roots (Hull 1995). It is commonly observed that abundant nitrogen stimulates shoot growth at the expense of root production. This produces grass plants that are less able to tolerate periods of drought and are more vulnerable to root diseases.

During most of the growing season, high nitrogen fertility decreases photosynthate translocation to roots (Fig. 2). This occurs because the presence of nitrate in leaves shunts photosynthetic products away from the formation of sugars and toward amino acid synthesis. Sugars would be translocated to sinks, including roots, but amino acids promote protein synthesis which stimulates vegetative shoot growth. The resulting energy starvation of the roots slows further nitrate uptake, which in turn decreases nitrate levels in the leaves and restores a more normal balance in photosynthate partitioning between amino acids and sugars and between shoots and roots. This feed-back control over nitrogen absorption helps maintain a healthy equilibrium between the growth of shoots and roots.

It is interesting that nitrogen stimulation of shoot growth, at the expense of root production, does not occur during the winter months when low temperatures inhibit shoot growth (Fig. 2). Thus, high soil nitrate levels during the cold months of the year do not inhibit photosynthate translocation to, or the growth of, roots. This explains why fall fertilization of turf, which may contribute to elevated soil nitrate levels, never causes an unfavorable root-shoot ratio during the following spring.

• *Leaf injury* - Anything that reduces the number and condition of source leaves will limit the photosynthate available for translocation to roots. We have already considered the negative impact of close mowing on root growth, but a similar case can be made for leaf diseases (dollar spot, brown patch, leaf spot, etc.) which reduce the amount of photosynthetically active leaf surface and limit the energy available for export to roots. The attack of leaf pathogens also induces various defense reactions; as a result, photosynthate is retained in the leaves for increased metabolism and the synthesis of protective phenolic compounds. Thus, less photosynthate is available for transport to roots. Injury by leaf feeding insects, excessive wear due to traffic or athletic activities, and salt or herbicide damage to leaves will all reduce root growth by limiting photosynthate production (source output). While a dense healthy turf does not guarantee energy transport to roots, it is difficult to obtain root growth in the absence of a healthy leaf canopy.

• *Allelopathy* - Some plants release chemicals from their roots which inhibit the growth of other plants. This phenomenon of chemical competition is called **allelopathy** and the inhibitors produced are **allelopathic chemicals**. Allelopathy is especially important in very dry climates where proper plant spacing is important. If plants crowded each other under such conditions, there would be insufficient water and all plants would die. The release of allelopathic chemicals maintains an inhibited zone around each plant which prevents crowding and insures adequate water and survival. Some weeds are allelopathic and will inhibit root growth of nearby plants, including turfgrasses. Turfgrasses can also produce inhibiting chemicals and thereby resist weed invasion. A dense turf of fine-leafed fescues appears to resist the encroachment of weeds probably due to allelopathic inhibition. Turfgrasses growing under the canopy of shrubs and young trees can severely inhibit their growth, again implicating allelopathic competition.

Little research on allelopathy has been conducted in turfgrass communities, but many observations strongly suggest that chemical inhibition is a factor. Allelopathy does not always involve living plants. Some allelopathic chemicals are released from decomposing plants. Indirect evidence suggests that some weedy warm-season grasses (crabgrass, goosegrass, etc.) will resist turfgrass recolonization of the soil on which they had been growing, even after they are killed by freezing temperatures. Water extracts from such dead plants have been shown to inhibit root growth of turfgrasses. Thus, the presence of weeds, even when dead, may inhibit the growth of turfgrasses, especially the reestablishment of their root systems.

• *Drought conditions* - Many environmental stresses will shift the partitioning of photosynthates from supporting shoot growth to enhancing root production. Drought has proven especially interesting in this regard. Several experiments have demonstrated that when the soil begins to dry, shoot growth becomes depressed well before any moisture stress can be detected (Davies and Zhang 1991). Apparently, when some roots growing near the soil surface experience drought stress, they begin to synthesize abscisic acid (ABA). This growth inhibiting hormone is transported to the leaves, where it causes stomates to close and slows shoot growth. With the shoot sinks demanding less photosynthetic product, more sugars are available for translocation to the roots. This provides the energy for renewed root growth, especially where moisture is adequate. The result is normally greater rooting depth, which makes more water available, thus further forestalling serious drought stress.

The enhancement of root growth as a result of periodic moisture deficiencies is a common observation. Apparently, the ABA signal sent from roots to shoots effectively warns the plant that the soil is becoming dry and that it should reduce its rate of water use and allocate more energy for root growth. In this way, the plant can respond to impending drought conditions by growing deeper roots and increasing its access to available water. While this response to drought has not been studied specifically in turf, it has been observed in other grasses and indirect evidence suggests that it does operate in turf. Turf that is irrigated according to soil water potentials, where the grass is subjected to mild drought stress between irrigations, has been observed to be more deeply rooted and to utilize less water than turf that is irrigated on a timer and never experiences drought.

Turf management strategies to promote root growth

Having established that growing good roots is consistent with sound turf management, is there anything that the turf manager can do to promote root growth? Obviously, the answer to this question is yes. However, like so much of good turf management, encouraging root growth involves many small considerations rather than a single practice; success is in the details and a constant awareness that root growth is important and should be factored into every management decision. Some practices to consider for promoting root growth are summarized below.

• *Species selection* - Some turfgrasses are known to produce deeper root systems than others. Table 1 shows root distribution, by depth, of five cool-season turfgrass species and indicates that perennial ryegrass and tall fescue are capable of deeper rooting than Kentucky bluegrass, creeping bentgrass or annual bluegrass. The tendency for annual bluegrass to experience injury during hot, dry conditions is understandable; since all of its roots are confined to the top 4 inches of soil, its capacity to

Table 1. Vertical distribution within the soil of roots from five cool-season turfgrasses*.

Soil depth	Annual bluegrass	Creeping bentgrass	Kentucky bluegrass	Perennial ryegrass	Tall fescue
(inches)			(%)		
0-4	100	42	75	33	35
4-8	-	41	20	28	34
8-12	-	17	5	29	23
>12	-	-	-	10	8

* Based on A.J. Koski as reported in Danneberger 1993

tap available water resources is clearly limited. Kentucky bluegrass and creeping bentgrass are less able to exploit soil water and nutrients than perennial ryegrass or tall fescue; as a result, these latter grasses would be preferred for sites with nutrient limitations or which are prone to drought stress.

Cultivar variation in rooting potential has also been observed (Table 2). Ten cultivars of Kentucky bluegrass were compared in the field during the late summer and early fall when their root systems were weakest. 'Enmundi' clearly exhibited greater root mass and enhanced photosynthate partitioning to roots (% ^{14}C-photosynthate recovered in roots). Unfortunately, Enmundi is not commercially available, but 'Rugby' and 'Brunswick' also appear to have some rooting advantage. It is not yet possible to compare most cultivars for their root growth potential, but eventually such information will become available especially if turf managers ask for it. It is encouraging that there appears to be genetic variation in rooting potential and that, eventually, it may be possible to match the grass cultivar with the conditions under which it will be grown.

• *Mowing height -* The importance of mowing height for root growth has already been discussed. However, there clearly are situations where turf use precludes adjusting cutting height as a management tool. Nevertheless, there are many situations, such as during periods of environmental or use stress, where if cutting height is raised it will promote greater root growth and increase stress tolerance. In lawn management, raising the cutting

Table 2. ^{14}C-photosynthate recovered in roots of ten Kentucky bluegrass cultivars 48 hours following exposure to $^{14}CO_2$*.

Cultivar	15 August		24 October	
	Root mass (g/dm^2)	% ^{14}C in roots (%)	Root mass (g/dm^2)	% ^{14}C in roots (%)
Kenblue	1.5	1.3	0.7	2.2
Parade	1.5	1.7	1.0	2.4
Touchdown	1.7	1.2	1.4	3.6
Merion	1.2	1.3	0.8	2.6
Nugget	3.6	1.6	1.2	3.1
Rugby	3.4	2.1	1.9	3.7
Victa	2.2	0.9	1.8	2.6
Baron	3.0	1.4	2.0	2.8
Brunswick	3.6	1.1	2.0	2.8
Enmundi	7.2	2.4	5.0	4.2

* From Mehall *et al.* 1991

height to more than 2 inches during the summer, and through much of the fall, will help maintain a more favorable balance between root and shoot growth. Lowering the cut before cold weather sets in will prevent dead grass from shading the green tissues below and allow winter photosynthesis to occur. A lower cutting height will also trap fewer tree leaves and prevent winter shading. When cutting height can be varied, it should be used as part of a root management strategy.

• *Fertility management* - Nitrogen is the fertilizer nutrient that has the greatest impact on root growth. Since high nitrogen levels tend to shunt photosynthate to shoot growth and away from roots, it is best to avoid excess nitrogen during periods when root growth already has a low priority for plant energy. Consequently, midsummer and early fall are not good times to apply nitrogen if root growth is a consideration. Since winter energy partitioning does not appear to be influenced much by nitrogen availability (shoot sinks being environmentally inhibited) late fall nitrogen applications should not inhibit root growth, although its efficiency of use might be questioned. Because nitrogen uptake during the spring is extremely rapid, soil nitrate levels remain low, independently of fertilizer application rates. However, since nitrogen applied in the spring promotes excessive shoot growth, it could initiate root decline earlier than when it would occur normally. Early spring nitrogen application is probably safe for all concerns. Frequent light applications of readily available nitrogen are preferred, but fewer, heavier applications of slow-release materials will have the same effect.

Phosphorous has been shown to promote lateral root growth in many plants. Whenever establishing a new lawn or renovating any turf, do not miss the opportunity to incorporate generous amounts of phosphorous and lime throughout the soil profile. Elevated soil pH will make the phosphorous more available and promote more extensive rooting. Of course, when renovating a sand based green, follow USGA recommendations; since it is not a soil medium, the principles of nutrient availability and plant response will be different.

• *Pest control* - Root health is not only controlled by source-sink relations within turfgrass plants, as pests can also play a major role. Insect feeding, competition from weeds and root infecting diseases can all decimate a turf root system. Unless such challenges are managed effectively, root promoting strategies will be of little value. While a healthy root system will help turf tolerate pest attacks, it should not be the main line of defense against pests. Managing turf for good root growth, however, can be a useful component of an integrated pest management program.

• *Stress management* - As mentioned above, stress conditions can, in some situations, promote root growth over shoot growth. Scheduling irrigation according to the soil water potential of the root zone (tensiometer reading) can stimulate deeper rooting and help conserve water. Raising the mowing height will also help conserve water, as well as promoting greater root growth. Shading will normally reduce energy partitioning to roots; this can be corrected, in part, by thinning the tree canopy and removing southerly positioned light barriers from the landscape. Poor drainage will encourage root rot and cause a chronic management problem. Promoting better water infiltration and raising the cutting height to increase transpiration will help, but an engineering solution is often required. Many stress problems can be minimized by proper design that is sensitive to turfgrass needs.

• *Root zone management* - Managing soil conditions as a means of promoting root development clearly cannot be overlooked. Adequate soil volume, in order to accommodate a plant's root growth potential, is essential. There is little to be gained in managing turf for root growth if there is no place for the roots to grow. A consideration, which is gaining acceptance, is expanding the root zone by converting subsoil. Frequently, subsoil layers are not penetrated by roots because of textural discontinuities or toxic aluminum levels. Deep plowing or perhaps coring can break up a loam-sand interface and promote better drainage, as well as eliminating anaerobic layers which form at such interfaces and discourage deep rooting. Liberal lime applications, thoroughly incorporated within the soil profile, will raise subsoil pH and make aluminum and manganese less available to grass roots. Both of these elements inhibit root growth. Incorporating organic residues will improve soil structure, increase cation exchange capacity (nutrient retention), promote improved aeration and chelate micronutrients, thus making them more uniformly available. However, grass roots alone will gradually increase soil organic matter and improve conditions for root growth. An entire article could be written on soil modification for optimum turfgrass growth, but these few ideas will make the point that soil management is not to be overlooked in developing a strategy for promoting root growth.

Root growth in warm-season turfgrasses

This entire discussion has centered on cool-season turfgrasses. Are roots equally important for the proper performance of warm-season grasses? Absolutely they are, possibly even more so since warm-season grasses do not regenerate their root systems during the fall and winter. Warm-season turfgrasses lose most of their roots during the winter dormant period. When spring temperatures increase too rapidly, sudden root death may eliminate all over-wintering roots. These grasses regenerate their root systems during the spring and maintain root growth throughout the summer. They can do this because their photosynthate production is not diminished by high photorespiratory rates. Thus, energy is available, even during the hottest days of summer, to support both shoot and root growth. This makes warm-season grasses much better adapted to summer conditions, which in turn makes root management less of a challenge.

The same basic ideas, regarding source-sink relations, outlined above, hold for the warm-season turfgrasses as they do for their cool-season cousins. Adverse soil conditions and uncontrolled pests can also take their toll of roots from warm-season grasses. Close mowing and excessive nitrogen will similarly reduce their root growth. In general, roots of all grasses must compete for photosynthetic resources with shoot sinks, rhizomes and stolons. Roots will receive their share only if turf management does not excessively stimulate shoot sinks or reduce source leaves to a level where energy supplies are insufficient to support root growth. The Southern turf manager faces similar problems in managing turf root systems, the only difference being the time of root growth.

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Terms to Know

Allelopathy - The chemical inhibition of one plant by a neighboring plant of the same or other species.

Phloem - Specialized vascular tissue within leaves, stems and roots by which photosynthate is translocated from sources to sinks.

Photorespiration - Light driven consumption of oxygen and release of carbon dioxide that occurs in leaves of cool-season plants under conditions of high temperature and light.

Photosynthate - The products of photosynthesis; usually sugars capable of being translocated from the sources in which they are made.

Sieve Tubes - Long tubes in the phloem composed of specialized living cells (sieve elements) through which photosynthate is translocated from source to sink organs.

Sink - Organs of a plant in which photosynthetic products are consumed for growth (roots, buds, flowers) or stored for future use (fruits, seeds, tubers, rhizomes).

Source - Photosynthetically active plant organs; usually fully expanded leaves, stems and other green structures.

Translocation - The process by which photosynthetic products are transported from source organs to regions of sink activity.