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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.

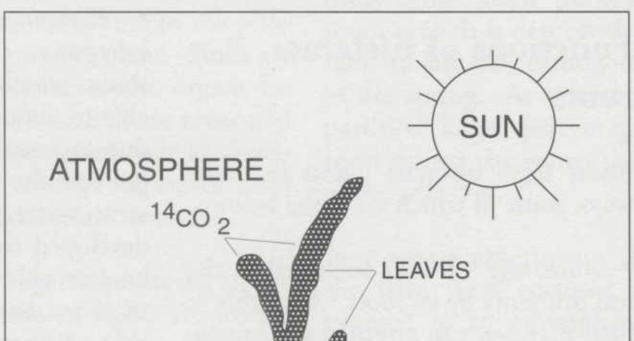

Figure 1. Source - sink relationships among organs of a turfgrass plant being exposed to carbon-14 labeled CO_2.

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

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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.

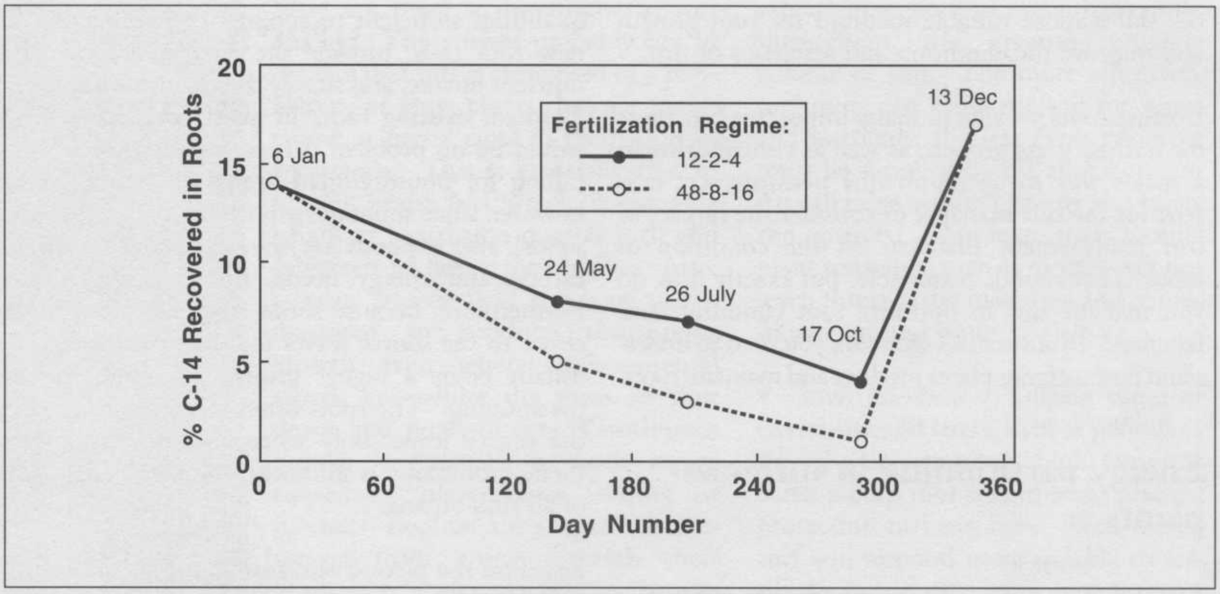

Figure 2. Percentage of ^{14}C-photosynthate recovered in roots of Kentucky bluegrass turf 48 hours after exposure to $^{14}CO_2$ at various times of the year.

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^{o} 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^{o} 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 Root mass (g/dm^2)	15 August % ^{14}C in roots (%)	24 October Root mass (g/dm^2)	24 October % ^{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.

Maximizing Disease Control with Fungicide Applications: The Basics of Turfgrass Fungicides

Part one: Fungicide Use and General Properties

by Eric B. Nelson
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By increasing already existing stresses on turfgrass plants, the overapplication of fungicides may make effective disease control nearly impossible. Typically, turf managers do not have sufficient available information with which to make proper fungicide selections, nor do they routinely monitor fungicide applications to determine their success or failure. In the first part of this ongoing series, I will review some basic concepts of turfgrass fungicides and how they work in controlling turfgrass diseases. Future articles will examine soil, plant, pathogen, and environmental factors affecting fungicide efficacy, as well as considerations to keep in mind, with application equipment, application strategies and recordkeeping, to enhance disease control with fungicides.

The application of fungicides has historically been the major tactic for controlling fungal diseases on high quality turfgrasses. In many cases, without the application of fungicides, golf course turfgrass management practices would not be what they are today. For example, the trends towards agronomically unrealistic cutting heights, the ever-increasing amount of traffic on putting greens, and the low nutrient inputs to maintain unnecessarily high green speeds, have placed unprecedented stresses on turfgrass plants, making them highly susceptible to damage from many different diseases, some of which were previously considered relatively unimportant.

Along with the increased stress imposed on golf course turf has come increased applications of fungicides. Today, golf course turfgrasses receive more fungicide inputs than any other agricultural or horticultural crop, with total dollars spent exceeding 20% of the total U.S. fungicide market (Table 1, Figure 1). The vast majority of these

Table 1. Breakdown of turfgrass fungicide use by market.

Total U.S. Fungicide Use
$450 Million
Turf and Ornamentals
$120 Million (26.7%)
Golf Course Turf
$90 Million (20.0%)
Lawncare and Landscape Turf
$10 Million (2.0%)

From: A. Talley, 1992.

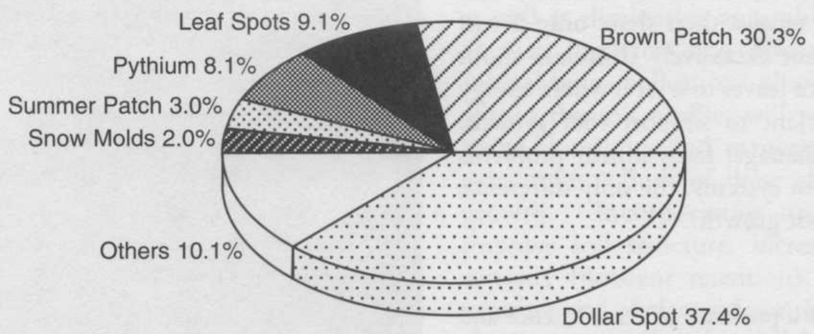

Figure 1. Breakdown of fungicide use on turfgrasses by disease.

applications are to putting greens and tees, making the amount of fungicide applied per unit area quite high. Without a doubt, this trend is being increasingly viewed, by the public at large, as environmentally irresponsible.

Because turfgrass plants in general, but on golf course putting greens in particular, are continually compromised, the level of disease control typically achieved with fungicides is less-than-desirable. In fact, nearly all disease control strategies are less than desirable on overly compromised turf. This often forces turfgrass managers to overapply fungicides, following the belief that "more is better." However, overapplication of fungicides may further intensify stresses on turfgrass plants, making effective disease control nearly impossible.

Often, in these situations, disease control is nothing more than a stroke of luck, usually accompanying a change in the weather toward conditions that are no longer ideal for optimum disease development. I am repeatedly amazed at how little thought goes in to applying fungicides, particularly to golf course turf, and how little turf managers understand the factors that influence the behavior and efficacy of fungicides.

Fungicide labels

One of the more overwhelming aspects of using and applying fungicides is understanding all of the information on the fungicide label. Being quite familiar with this information is not only a legal responsibility, but it will also help you, as an applicator, to make more effective applications and reduce detrimental environmental and health-related side-effects. The label serves several purposes: 1) to identify the chemicals involved; 2) to identify the uses for which the product is registered; 3) to describe the recommended dosages for specific disease problems; and 4) to identify any potential human and environmental hazards, and any incompatibilities or phytotoxicities. The label consists of the printed material on, attached to, or accompanying the fungicide container and should be read thoroughly before use.

The most obvious part of any fungicide label is the trade name of the fungicide. This is the name the manufacturer assigns to the product. It has little to do with the actual chemical ingredients in the container. For any given fungicidal compound, there may be many different trade names, depending on the target crops and the company manufacturing the particular formulation. Other, more obvious, parts of the fungicide label include the chemical name of the active ingredients (inert ingredients will be listed as well), the formulation, signal words indicating the relative human toxicity, and general information on use, reentry, storage, disposal and safety.

One of the more apparently trivial, but perhaps one of the more important, parts of the fungicide label is the Environmental Protection Agency (EPA) registration number. The fact that the number is on the label signifies that this material is indeed a pesticide, and not a product intended for any other use. There is a unique EPA registration number for every individual product and formulation; its presence on the label represents an endorsement by the EPA that the product will do what the manufacturers claim it will do. There are a number of products on the market that make claims about disease control. However, only those that carry an EPA registration number can be used legally for the control of specific turfgrass diseases.

Labels should be consulted before mixing and applying turfgrass fungicides. For example, you should read the label to fully understand what protective equipment to use and the compatibilities of the fungicide with other pesticides, adjuvants, growth regulators, and fertilizers. Often, on turfgrass fungicide labels, two different application rates will be listed: a preventive rate (usually the lower labeled rate) and a curative rate (the highest labeled rate). The terms preventive and curative are quite inappropriate, since neither rate is necessarily preventive and by no means is the higher rate curative. If at all possible, the lower rate is always preferred, since it reduces the total environmental load of the fungicide. Based on the label rates used, the total amount of fungicide to be applied should be accurately calculated and the proper mixing and safety procedures followed.

It is important to remember, that under no circumstances should a fungicide be used in a manner that is inconsistent with what is outlined on the label. This is not to be taken lightly, since the rules and regulations governing pesticide use in general, as well as the enforcement of those rules, are likely to stiffen in the future.

Fungicide formulations

Turfgrass fungicides are never sold as just the toxic fungicidal compound. They are always mixed with other so-called inert ingredients to make them easier to handle, apply, and store (Table 2). On all fungicide labels are listed the percentage of the formulation that is composed of the active ingredient and inert ingredients. In nearly every case, the inert ingredients make up the largest part of the fungicide formulation. Some are anything but inert, particularly those in emulsifiable concentrate formulations where the "inert" ingredients are petroleum-based solvents, some of which are quite harmful to human health, such as benzenes, naphthalenes, and xylenes. Unfortunately, the inert ingredients are rarely specified on the label.

Table 2. Formulations of turfgrass fungicides.

Abbreviation	Type of Formulation
AS	Aqueous solution
DF	Dry flowable
E or EC	Emulsifiable concentrate
F or FLO	Flowable
G	Granular
SC	Soluble concentrate
W or WP	Wettable powder
WDG	Water dispersible granule
WSP	Water soluble packet

Historically, the most common types of formulations for turfgrass fungicides have been granular and wettable powder formulations. These are dry formulations in which the fungicidal compound is placed on particles or granules of clay or other types of dried plant material. Granular materials have the advantage of being applied in a dry form. This is particularly advantageous when applications are made at times of the year, particularly in the northern areas of the U.S., when irrigation systems may be shut down. Wettable powder formulations need to be mixed with water, where they form a suspension that can be sprayed.

Whereas the ability to make spray applications is a positive attribute of wettable powder formulations, the main negative aspect of their use centers around the generation, during weighing and mixing operations, of considerable amounts of dust. This presents an unnecessary inhalation danger for applicators. To overcome this negative aspect, manufacturers have developed water dispersible granules (or dry flowables), flowables, and water soluble packets. In addition to reducing the dust problem, these formulations also allow for more accurate measuring. Regardless of whether wettable powders, flowables, water dispersible granules or water soluble packets are used, the fungicide formulation is such that it forms a suspension, and not a solution, in water. The material, therefore, must be constantly agitated in the spray tank, to avoid settling of the suspended particles, and care must be taken to keep spray nozzles unclogged.

Among the more common formulations of many of the newer fungicides are emulsifiable concentrates. These formulations consist of the active fungicidal ingredient dissolved in a petroleum based solvent that, when mixed with and agitated in water, forms an emulsion. Petroleum-based solvents are more suitable for dissolving the fungicide, since many of the active fungicidal ingredients are not readily soluble in water. Furthermore, these formulations also avoid the problems of dust generation and nozzle clogging. Unlike the wettable powders, flowables, and water soluble packets, for which the active ingredients are specified as a percentage of the total formulation, the active ingredient in emulsifiable concentrates is expressed as pounds of active ingredient per gallon of formulation.

The type of formulation used may affect the overall efficacy of the fungicide. In particular, granular formulations seem to be less effective, as a general rule, than other sprayable fungicides with the same active ingredient. For example, granular formulations of contact and localized penetrant fungicide, used for the control of foliar diseases of turfgrasses, may require substantially more applied active ingredient than a spray application to achieve the same level of disease control. Generally, the systemic penetrant fungicides are more effective than the contact fungicides when formulated as a granular product. On the other hand, when applied for the control of root and crown diseases, granular formulations, by providing a slow release of fungicide right at the crown area, can be quite effective.

Types of turfgrass fungicides

Fungicides used for turfgrass disease control can be categorized either as contact or penetrant fungicides. Many of the older products consisted primarily of contact fungicides. Examples of these include anilazine, chlorothalonil, etridiazole, mancozeb, quintozene, and thiram. Contact fungicides are typically applied to foliage to prevent pathogenic fungi from infecting foliar tissues. However, these fungicides are also effective in killing pathogens in the root and crown area as long as the fungicide can be delivered properly to that area.

Contact fungicides are generally capable of killing both dormant spores, and dormant and active mycelium of pathogenic fungi. They must, however, be reapplied frequently so that newly formed grass tissues remain protected. In order for contact fungicides to be effective foliar protectants, they must be allowed to dry on the plant surface after application. Therefore, in order to achieve the most effective control of foliar diseases with contact fungicides, they should never be watered-in or applied in the rain. If, on the other hand, they are being used to control pathogen activity in thatch or in the root zone, they should be watered-in. More specific aspects of post-application treatments will be covered in a later part of this series.

The majority of fungicides presently used for turfgrass disease control are penetrant fungicides. This means that they are absorbed to varying degrees by the plant tissues to which they are applied. For systemic penetrant fungicides, they can move in the plant vascular system from the original site of application to other distant plant parts. Most of the currently used systemic penetrant fungicides are translocated upward in the plant. These would include all of the sterol inhibiting and benzimidazole fungicides (Table 3), as well as metalaxyl and flutolanil. A few turfgrass fungicides have only

Table 3. Movement of turfgrass fungicides in plants.

Movement Type	Fungicide
Contacts (No internal movement)	Anilazene Chloroneb Chlorothalonil Etridiazole Mancozeb Quintozene Thiram
Localized Penetrants (Little significant movement)	Iprodione (limited) Propamocarb (limited) Vinclozolin (limited)
Systemic Penetrants (Mostly upward movement)	Benomyl Cyproconazole Flutolanil Fosetyl Al (up/downward) Metalaxyl Propiconazole Thiophanate Methyl Triadimefon
Modified from Couch, 1995	

limited movement away from the site of plant uptake. These would include the dicarboximide fungicides iprodione and vinclozolin, and the carbamate fungicide propamocarb. Only one turfgrass fungicide, fosetyl Al, has significant downward movement.

The way in which systemic penetrant fungicides move inside the plant influences the manner in which they should be applied in order to maximize their effectiveness. These properties should be taken into consideration when developing any sound disease control strategy that includes systemic penetrant fungicides. In general, foliar disease control with systemic penetrant fungicides is more prolonged when the fungicides are drenched into the root zone. For example, foliar applications of systemic penetrant fungicides provide excellent short-term control of foliar diseases, whereas drenching the fungicide into the root zone provides a much longer period of protection, as well as control, against root and crown diseases. On the other hand, root disease control with systemic penetrant fungicides is only possible if they are drenched into the root zone.

Penetrant fungicides have the advantage over contact fungicides in that they generally have a longer residual action. For example, only 3 - 10 days of control can generally be expected from a contact fungicide, which means that it takes only 3 - 10 days for the disease to reappear following the fungicide application. On the other hand, penetrant fungicides may provide at least 21 - 28 days of control. In addition to protecting newly-formed plant tissues, penetrant fungicides have the added advantage of being able to suppress pathogens that have already infected plant tissues.

None of the penetrant fungicides currently on the market actually kill turfgrass pathogens. They simply prevent them from growing. This is usually accomplished through a very specific mode of action (Table 4), which potentially can lead to serious problems of fungicide resistance. This will also be discussed in a later installment to this series.

Decades ago, in order to achieve effective disease control with fungicides, there was little technical knowledge required of a turfgrass manager. This was because many of the older materials such as mercury- and cadmium-based fungicides had little or no selectivity and were considered to be general biocides, killing most everything living in soil. Other currently-used contact fungicides such as anilazene, mancozeb, and thiram also have little selectivity, but are generally much less toxic than the cadmium and mercury fungicides. A number of the newer penetrant fungicides are either so selective that only certain taxonomic groups of turfgrass pathogens are affected (e.g., metalaxyl, foestyl Al, and propamocarb), or they are quite broad spectrum, eliciting many negative side-effects (see *TurfGrass TRENDS*, May 1995).

It is often difficult to know how these fungicides will behave in turfgrass soils and how plants will respond, without knowing more about the properties of the fungicides, the behavior of turfgrass plants, the physical and chemical properties of the soil, and the level of microbial activity in both thatch and soil. As a result, achieving effective disease control while, at the same time, minimizing environmental impacts, requires a significantly higher level of technical expertise.

How fungicides work

Fungicides are designed to disable fungi by inhibiting a number of metabolic processes in fungal cells. The cellular location and the biochemical pathway or enzyme, inhibited by the toxic action of the fungicide, imparts some selectivity upon the fungicide being used. The specific modes of action of a number of currently available turfgrass fungicides are listed in Table 4.

Turfgrass fungicides can all be grouped according to their general chemical class. Currently, there are ten different classes for turfgrass fungicides. The different fungicides found within each class all possess similar mechanisms of action, whereas fungicides in different classes have different modes of action. The only exceptions to this rule are the fungicides found in the aromatic hydrocarbon and dicarboximide groups. Fungicides in each of these groups have very similar modes of action.

Fungicides suppress the activity of fungal pathogens either by killing fungal cells (fungicidal) or by simply suppressing growth and reproduction (fungistatic). Those fungicides that affect cell properties and processes common to a wide variety of organisms, such as nuclear function or mem-

Table 4. Mode of action of turfgrass fungicides.

Fungicide Class	Fungicide(s)	Function Affected	Biochemical Pathway or Enzyme Inhibited
Aromatic Hydrocarbons	Quintozene Chloroneb Etridiazole	Membrane Function	Lipid peroxidation, cytochrome c reduction
Benzimidazoles	Benomyl Thiophanate Methyl	Nuclear Function	Microtubule Formation (affects meiosis and mitosis)
Carbamates	Mancozeb Propamocarb Thiram	Membrane Biosynthesis	Unknown
Carboximides	Flutolanil	Respiration	TCA cycle (succinate dehydrogenase complex)
Dicarboximides	Iprodione Vinclozolin	Membrane function	Lipid peroxidation
Nitriles	Chlorothalonil	Respiration	TCA Cycle (Electron Transport)
Phenylamlides	Metalaxyl	Nucleic Acid Synthesis	RNA polymerase I
Phosphonates	Fosetyl-Al	Amino acid metabolism (Fungi) Improved host defenses (Plants)	Unknown
Sterol Biosynthesis Inhibitors	Cyproconazole Propiconazole Triadimefon Fenarimol	Membrane Function	Ergosterol Biosynthesis
Triazines	Anilazene	Nonspecific Cell Toxicity	Unknown

Compiled from Köller, W., Ed. 1992. *Target Sites of Fungicide Action*, CRC Press, Boca Raton, 328 pp.

brane biosynthesis, generally have a wider spectrum of activity than do those affecting more specific functions, such as specific respiratory enzymes, etc. These broad spectrum contact fungicides would include chlorothalonil, mancozeb, and thiram, as well as the broad-spectrum systemic penetrant fungicides, such as the benzimidazoles (benomyl, thiophanates) and sterol inhibitors (triadimefon, propiconazole, etc).

Achieving the maximum levels of disease control from fungicide applications

The goal of any fungicide disease control program should be to deliver the minimum dosage of the most effective fungicide to the target, at the proper time, and with as few negative side-effects as possible. In order to maximize the efficacy of the fungicide, we need to consider a number of soil, plant, environmental, equipment, and fungicide factors. Failure to do so will result in less-than-adequate levels of control or undesirable side-effects.

Turfgrass managers are generally of the opinion that when all else fails, you should rely on fungicides for the control of diseases; this is due to a belief that fungicides do not fail. However, it is seldom recognized that fungicide applications do indeed fail, sometimes more often than we would like to believe. In some cases, the failure is beyond our control, especially when conditions for disease development are so favorable that few, if any, control strategies would be effective. In other cases, the failures could easily be avoided with a little thought and planning.

When less-than-adequate control is observed, the failure is generally considered to be a result of a mistaken diagnosis, in which case another fungicide is chosen, only to inevitably fail again. At this point, the turf manager usually panics and begins to apply every fungicide in his or her pesticide storage facility. Finally, when nothing else works, a call is made to the nearest turfgrass pathologist for diagnosis and advice. Of course, by this time there is little a turf pathologist can do.

The following are some of the more important reasons for fungicide failures:

1. Lack of or improper diagnosis (see *TurfGrass TRENDS*, July 1995 issue)
2. Applicator errors resulting in:
   a. improper rates and frequencies
   b. physical, chemical, and placement incompatibilities
   c. in-tank degradation
   d. improper delivery (e.g., not watered-in, not allowed to dry on foliage, incorrect timing, etc.)
3. Improperly calibrated application equipment resulting in:
   a. improper coverage
   b. incorrect delivery rate
4. Significant levels of fungicide adsorption or degradation in soil, preventing the material from reaching the target pathogen
5. Overly-stressed turf
6. Undesirable non-target effects (i.e. disease trading or pathogen resistance) (see *TurfGrass TRENDS*, May 1995 issue)
7. Unusually favorable conditions for disease development
8. Incorrect choice of fungicide (e.g., not effective against the target pathogen)

These factors must be considered in attempting to maximize the effectiveness of fungicide applications. Aside from the applicator, perhaps the most important consideration in maintaining highly effective fungicide programs is obtaining a correct diagnosis. Without a proper diagnosis, no fungicide application will be successful. The second most critical factor is the application equipment itself. If not in proper working order and correctly calibrated, the equipment will fail to accurately deliver the fungicide to the target and the application will not be successful, despite every attempt to address the other important factors listed above. As an applicator, every effort should be made to be as meticulous as possible when choosing, measuring, mixing, and applying fungicides to highly valued turf areas. In the coming months, these and other topics, related to maintaining effective fungicide programs, will be covered in considerable detail by *TurfGrass TRENDS*.

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Terms to Know

Active ingredients - the main inhibitory substance found in a fungicide formulation.

Biosynthesis - the process by which living cells make molecules, tissues, or organs.

Contact fungicide - those fungicides that are active only on the external parts of plants.

Emulsion - suspension of liquid droplets within another immiscible liquid.

Formulation - all of the ingredients and additives making up a given fungicide product.

Fungicidal - treatments that kill fungal pathogens.

Fungistatic - treatments that prevent fungal pathogens from growing or producing spores, or prevent spores from germinating.

Inert ingredients -those components of a formulation that have no fungicidal activity.

Label - all of the written information that accompanies the fungicide. This includes the information affixed to the container, as well as any other written material associated with the product.

Localized penetrant - those fungicides that pass into the tissue underlying the point of application.

Penetrant fungicide - those fungicides that enter plant tissues.

Systemic penetrant - those fungicides that pass into the plant tissues and are moved through the xylem and phloem to distant parts of the plant.

FOR A COMPLETE INDEX OF TURFGRASS FUNGICIDES AND MANUFACTURERS CONTACT:

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U.S. Environmental Protection Agency and Turf Organizations Form Partnership

by Sherry L. Glick and Anne Leslie
U.S. Environmental Protection Agency

The Pesticide Environmental Stewardship Program (PESP) is the U.S. Environmental Protection Agency's (EPA) voluntary program designed to address the use of, and risk associated with, pesticides. It is involved in making administrative, regulatory and legislative changes to encourage the use of safer pesticides. A major element of PESP is the encouragement of voluntary partnerships with private industry, on behalf of safer pesticides and environmental stewardship. All organizations with a commitment to pesticide risk/use reduction are eligible to join PESP, either as a Partner or Supporter.

One of the components of PESP is the development of regional environmental stewardship strategies. EPA plans to integrate the strategies developed by the Partners into its policies and programs for agriculture and the environment. Partners have a great deal of flexibility in developing their strategies. First, they identify their pest management issues, then they identify the potential solutions to those issues. Many Partners are close to completing their strategies, which will include research, education and alternative techniques and practices to enhance pest management and reduce pesticide use and risks.

Several turf organizations are participating in PESP. The Golf Course Superintendent's Association of America (GCSAA), the Professional Lawn Care Association of America (PLCAA), and the Pebble Beach Corporation are all participating as PESP Partners. Each of these organizations is developing its strategy for pesticide risk/use reduction.

The United States Golf Association (USGA) is participating in PESP as a Supporter. According to USGA President, Reg Murphy, "We were very pleased that the EPA has asked us to join this cooperative effort. USGA has committed millions of dollars over many years to develop turfgrasses that use substantially fewer pesticides. At the same time, we've also spent millions of dollars to study our game's impact on the environment, including what effect, if any, that golf course pesticide use has on our surroundings. This new Partnership can only enhance our ongoing efforts on these issues." It is the intent of USGA, as a PESP Supporter, to disseminate money for research to 1) produce turfgrasses which substantially reduce water use, pesticide use, and maintenance costs; 2) develop management practices for new and established turf which protect the environment while providing quality playing surfaces; and 3) encourage young scientists to become leaders in turfgrass research. This information is shared through educational publications, training seminars, and on-site visits to golf courses. The information gathered through research programs will further the knowledge base of the turfgrass industry. New grasses are released that benefit the golf industry and beyond, such as sports fields, parks and home lawns. New and developing information is also shared through a wide variety of educational programs that reach both the turfgrass industry and the general public.

GCSAA is taking the lead in discussions of environmental issues surrounding the game of golf. The Allied Associations of Golf, together with a number of environmental groups at Pebble Beach, California, met January 1995, to discuss environmental issues surrounding golf course development and operation. From this conference, "Golf and the Environment: Charting a Sustainable Future," a Guidelines Subcommittee was formed to develop a document, "Environmental Principles for Golf Courses." GCSAA prepared a draft document on principles in golf course management, which has been presented to the Allied Associations, and, subsequently, to the Guidelines Subcommittee. The subcommittee includes representatives from a number of organizations: GCSAA, USGA, Royal Canadian Golf Association, American Society of Golf Course Architects, the National Wildlife Federation, the American Farmland Trust, the National Coalition Against Misuse of Pesticides, the National Audubon Society, the Sierra Club, the New York Audubon Society, and the National Resource Defense Council. The subcommittee has made significant progress in coming to consensus on the document, which encompasses some critical issues in site selection for golf courses. The goal is to present a final draft document at the annual meeting of GCSAA in February, 1996, and to recommend its adoption at the next Summit meeting in March.

Earlier in the year, some of our PESP Partners were awarded grants which provided them the opportunity to design projects that would promote pesticide risk/use reduction. PLCAA was awarded a grant to educate and encourage lawn care companies to take measures that reduce the risk of pesticides to applicators, the public and the environment. The main component of the grant will be to develop a plan with a list of practices for each company to follow and evaluate against its own practices. The plan will outline those practices that are considered environmentally sound and directly or indirectly lead to the reduction of pesticide risk. Each practice will be assigned a range of points that can be credited to a company. If their total credit adds up to a predetermined total, they can be designated an EPA/PLCAA partner in the program for a specific time. In order to continue in the program past the first period, the participating company must submit a plan for adding measures that reduce the risks from pesticides. A committee will evaluate and determine compliance with the program, and if deemed necessary, visit the company facility or make an inquiry to ensure that companies follow through with their proposed practices.

Some examples of practices that can be adopted are:

- outreach training of homeowners, groups, organizations, and school children in environmentally sound lawn care practices;
- company posting on all properties that they treat when the state does not require it; and
- the use of spot applications, in lieu of broadcast applications, on a certain percentage of lawns and a certain percentage of a company's customer's lawns.

PLCAA believes that these activities can help industry implement and administer more planned and thoughtful activities for companies, as well as become more aware of practices that can be beneficial to their employees, customers and the environment.

If you would like to learn more about PESP, contact the PESP INFOLINE 1-800-972-7717 or the following:

PESP Partners:
PLCAA
contact: Tom Delany 1-770-977-5222

GCSAA
contact: Cynthia Kelly 1-800-472-7878

PESP Supporters:
USGA
contact: Kimberly Erusha 1-908-234-2300

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Ms. Anne Leslie has been a chemist in the Office of Pesticide Programs of the U. S. Environmental Protection Agency (EPA) since 1980. She has degrees in chemistry and biochemistry from, respectively, the University of Arizona and McGill University in Montreal and has done graduate work towards a Ph.D. at the University of Utah. She joined the EPA's Integrated Pest Management (IPM) Program in 1986, working on collecting and dissemination information on best management practices for turfgrass. This is her first contribution to *TurfGrass TRENDS.*

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