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Rhizosphere Microbiology

The Mysterious World of the Turfgrass Root Zone

F.B. Holl
The University of British Columbia

Intensive turfgrass management has traditionally focused on the application of a repertoire of primary and secondary cultural activities to maintain the appearance and functionality of a population of turfgrass shoots to a prescribed standard. In short – we manage the green part! That obsession with the grass shoot reflects what I refer to as "iceberg management." In closely mown turf, roots represent a significant, but largely invisible component of the plant ecosystem that is being managed. Just as the captain as the Titanic discovered the significance of what could not be seen, there is increasing evidence that turfgrass managers must become 'root managers' and that an important element of that management will relate to the plant root-soil microbe interaction.

In an earlier issue of *Turfgrass Trends*, Hull (February 1996) discussed the importance of roots to the grass plant and outlined management strategies for enhancing root growth. Roots function to anchor plants, in the absorption of water and nutrients, as a factor in stress tolerance and as a contributor of organic matter to the soil nutrient pool. Establishing and maintaining healthy

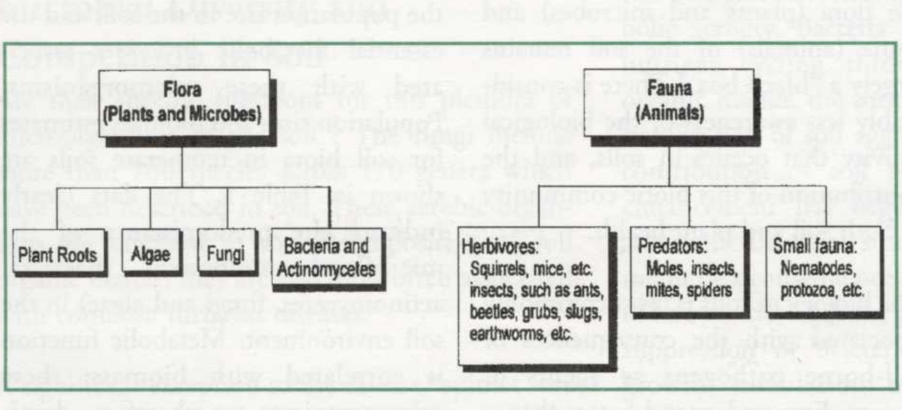

Figure 1. Diversity of soil flora and fauna in soil. *Reprinted with permission from Intro. to Turfgrass Management. UBC Continuing Studies, Vancouver BC.*

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TurfGrass TRENDS •7500 Old Oak Blvd. • Cleveland, OH 44130-3369
Phone: 440-243-8100 • Fax: 440-891-2675 • e-mail: knoop@mt-vernon.com

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TurfGrass TRENDS

Editor, William E. Knoop, Ph.D.
903-860-2239; 903-860-3877 (fax)
knoop@mt-vernon.com

Production Manager
Linda O'Hara
218-723-9129; 218-723-9576 (fax)
lohara@advanstar.com

Circulation Manager
Karen Edgerton
218-723-9280

Layout & Production
Bruce F. Shank, BioCOM
805-274-0321

Group Editor
Vern Henry

Group Publisher, John D. Payne
440-891-2786; 216-891-2675 (fax)
jpayne@advanstar.com

CORPORATE OFFICE
7500 Old Oak Blvd.
Cleveland, OH 44130-3369

EDITORIAL OFFICE
P.O. Box 1637
Mt Vernon, TX 75457

Abstracts: *800-466-8443*
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root function is an important part of turfgrass management. That emphasis was reinforced by comments in the September 1997 issue of the Golf Course Superintendents Association of America *Newsline*. Keith Karnok, a University of Georgia turfgrass scientist is quoted, "So much attention is given to the aboveground plant. But the plant that you can see is only as good as its roots. It's imperative to have a good root system, especially during stress conditions such as in a drought system. It's the roots that really save the plant."

The importance of roots may also be a function of their significant contribution to total biomass production in perennial plant species. Studies of natural grassland vegetation confirm that root production is a major component of total biomass. In a managed turf system where regular removal of shoot tissue is the norm, the root contribution to the plant-soil ecosystem might be even more substantial.

The Underground "Black Box"

While we understand much about the relationship between shoot and root growth, and about the response of roots to a variety of management strategies, the interaction of roots with the flora (plants and microbes) and fauna (animals) of the soil remains largely a "**black box.**" There is considerably less awareness of the biological activity that occurs in soils, and the contribution of this biotic community to both soil and plant health.

The biology of soils is most commonly associated with the consequences of soil-borne pathogens as agents of disease. Few understand better than a turf management professional the potentially devastating impact of such diseases on a turf stand. Under intensive management, turf is maintained in a tenuous balance between an attractive playable surface, and disaster. Furthermore, while the consequences of disease are often manifested in deteriorating shoot appearance and performance, many of the causative agents spend all or part of their life cycle in the soil, and use the roots as a vehicle of entry into the plant tissue. However, the prominence of disease as an on-going threat has often diverted our attention away from the beneficial aspects of the turf-soil biological relationship.

The flora and fauna of the soil encompass a diversity of organisms (Figure 1) which participate in essential ecological processes such as organic matter decomposition, nutrient transformations, pathogen antagonism and plant growth promotion. This wide-ranging combination of plant, animal and microbial species form the complex food webs that exist in the soil.

The focus of this article will be to examine the characteristics of the turfgrass root zone, and its interaction with the soil biotic community - particularly the microbial component of that community. That focus on soil microbiology is, in part, a function of the population size in the soil, and the essential metabolic processes associated with these microorganisms. Population sizes and biomass estimates for soil biota in temperate soils are shown in Table 1. The data clearly indicate the predominance of the microfloral component (bacteria, actinomycetes, fungi and algae) in the soil environment. Metabolic function is correlated with biomass; these microorganisms are, therefore, dominant contributors to the metabolic

Table 1. Population and Biomass Estimates for Biota in Temperate Soils

Organisms	*Number/m2*	*Biomass (kg/HFS)*
Bacteria	1013 - 1018	400-5000
Actinomycetes	1012 - 1017	400-5000
Fungi	1010 - 1016	1,000-15,000
Algae	109 - 1014	56-1,000
Protozoa	109 - 1016	17-500
Nematodes	106 - 109	17-400
Earthworms	30 - 7000	100-2,000

HFS = hectare furrow slice. The volume of soil in one hectare approximately 15 cm deep.

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activity that occurs in the soil ecosystem. The data also demonstrate the variability of numerical and mass estimates that have been reported for populations of soil microorganisms. Such variation is, in part, a reflection of the technical challenges of measuring such populations. However, for practical turf management, the significance of variable population size is its relationship to geographic location, soil type and cultural practices. If we are to understand and exploit these microbial populations for the production and maintenance of a healthy turf then it is essential to understand the characteristics of their habitat (the rhizosphere) and the nature of the population (numbers, diversity and metabolic activity).

Microbial Diversity and Competition in Soil

Are their specific functions for this plethora of microorganisms in the soil ? The fungi include more than 700 species across 170 genera which have been described in soil. These aerobic organisms are involved in the decomposition of soil organic matter; they are also most often associated with common turfgrass diseases.

A significant exception to the disease "epithet" are the mycorrhizal fungi - species which invade the plant root and develop a beneficial symbiotic relationship. The plant supplies photosynthetic carbon to the microbe for growth, while the mycelial network of the fungus extends the plant root system into the soil environment. Surface area increases up to ten-fold might result from this mycelial extension. The additional surface area facilitates nutrient uptake of immobile elements such as phosphorus.

Enhanced water and micronutrient uptake, as well as stabilization of soil aggregates, have also been reported as consequences of mycorrhizal activity. Sand profiles are likely to be deficient in mycorrhizal populations However, the development of commercial mycorrhizal inoculants has been limited and responses to inoculation have been variable. The development of mycorrhizal infections appears to occur most effectively through natural inoculation over time.

The aerobic actinomycetes ("filamentous" bacteria) are common inhabitants of moist, warm, well-aerated soils, although they are able to retain activity under drought conditions. Actinomycetes are important contributors to organic matter decomposition, particularly since they can degrade more complex constituents such as cellulose, chitin and phospholipids. In addition, many of these species produce antibiotic compounds `that can suppress or kill associated microbes, and might contribute to some of the natural "biocontrol" relationships observed in soils. There has been little or no attempt to manage the actinomycete component of soils.

The bacterial populations in the soil ecosystem can be significant in number, diversity and metabolic activity. Bacteria play an essential role in nutrient cycling through the breakdown of organic matter, the formation of humus, and the stabilization of soil aggregates. More recently the contribution of soil bacteria to plant growth enhancement has begun to receive additional attention. Bacterial stimulation of plant growth might be a consequence of one or more of a variety of known mechanisms; phosphorus solubilization, suppression of deleterious bacteria, and direct growth stimulation by production of plant growth-promoting substances have been described. The magnitude and importance of these soil bacterial populations have made them the focus of increasing research into their relationship to plant growth and health.

The enormous diversity, both within and among the populations of microbial constituents in the rhizosphere, creates a highly competitive environment, particularly under the substrate limitations that are often a condition of the system. Bacteria tend to thrive on simple organic compounds, typical of the simple exudates released by plant roots into the rhizosphere. Fungal and actinomycete populations are more likely to be enhanced when competition is mediated by the presence of more complex organic compounds.

What is the Rhizosphere ?

The term "rhizosphere' was first introduced by the German scientist Hiltner in 1904 to describe the volume of soil surrounding roots in which bacterial growth is stimulated; we often use the term now to describe "soil under the influence of plant roots." The terminology distinguishes this environment from soil without vegetation, or soil far enough removed from the roots to be outside their sphere of influence. The fibrous root system of a grass stand produces a substantial volume of rhizosphere soil in the turf ecosystem.

While we recognize soil as an important component of the nutrient/water systems that support plant growth, the characteristics of the soil as an environment for microbial life are less well established outside of the scientific community. Soil is a complex habitat for microbial growth with a high ratio of solid (minerals, organic matter and living microbes) to liquid (water). The tripartite solid phase is a complex mixture of components, which exist both separately and in mixed conglomerates. The liquid phase, which conveys nutrients and inhibitors, is normally not continuous in the soil except after rain, snow melt or under extensive irrigation. The discontinuity in this liquid phase can restrict microbial movement and might produce localized accumulations of nutrients and/or toxins, which affect plant growth. Gas movement in the soil might also be restricted by water status, producing localized accumulations of gases such as CO_2 (carbon dioxide) and CH_4 (methane), as well as depleted O_2 (oxygen) levels. These changes can alter the composition and activity of rhizosphere populations by influencing the proportion of aerobes, anaerobes and microaerophiles. Such changes can lead to significantly different kinds of biological activity. For example, the development of black layer under low oxygen tension in areas of the soil.

Microhabitats for Microorganisms

The microbes that inhabit the soil are essentially aquatic organisms - they proliferate in those habitats which have available water. Substantial microbial populations are normally developed in association with the clay and organic matter fractions of the soil system. Clay and other soil separates associate to form aggregates which are stabilized by organic components of the system. These aggregates retain water and develop niches for microbial development. The type of clay minerals involved in this aggregation can influence microbial growth and nutrition, spore germination and competition. It can also provide some physical protection against environmental fluctuations which might expose the organisms to acidity, heavy metals, temperature and desiccation. These microhabitats are highly variable and heterogeneous, but their importance to effective microbial population development is vital.

The development of the sand-based root zone has provided a welcome solution to many problems associated with poor drainage and compaction, but that performance comes at a price. Sand does not retain surface water films effectively, nor does it aggregate easily to develop the microhabitats that are so critical to effective rhizosphere microbial population development. This paucity of microbial activity is particularly critical during the establishment phase of turf. The development of a resilient turf-soil ecosystem with an effective rhizosphere microbial population does not likely occur for three to five years after seeding. The degree of that development is influenced by management and use during that period. The newly seeded, sand-based root zone is normally managed to maintain an adequate (sometimes excessive) supply of plant available nutrients and water. Economic pressures for early use might place additional stress on an otherwise fragile soil ecological environment which is unable to provide the necessary resilience to support the plant population. A significant element of that ecological resilience is contributed by the rhizosphere microbial population. These defective soil ecosystems are analogous to a human with a compromised immune system - they are incapable of an effective response to external challenges (environmental stresses, disease organisms etc.) In this state, many of the strategies which might normally be invoked to treat problems are not only ineffective, but could ultimately exacerbate the imbalances that already exist.

Soil Factors Influence Microbial Populations

In the rhizosphere a variety of factors are known to contribute to the activity, ecology and populations dynamics of soil microbes. Carbon and energy sources, mineral nutrients, growth factors, ionic composition of the soil solution, available water, temperature, atmospheric pressure and composition, pH, surface and spatial relations and the genetics of the microbes themselves all play a role in determining what microbes will proliferate in the rhizosphere.

The rhizosphere environment is characterized by an abundance of mucilaginous material and soluble organic compounds derived from epidermal plant cells and microbial activity. These constituents supply a unique combination of microbial substrates in the rhizosphere. Furthermore, many of these compounds interact with the rhizosphere soil to bind clay and humic aggregates into the secondary structure so essential for the development of microhabitats and enhanced microbial function. This complex heterogeneous environment might be illustrated by looking at the range of activity along the different portions of a root segment (See Figure 2).

Superimposed on this static perspective of the root-soil relationship, is the reality that these rhizosphere relationships are in a constant state of dynamic flux as roots develop and turnover, and as microbial populations evolve. Both spatial and temporal variation in the carbon compounds associated with root development in the soil occur

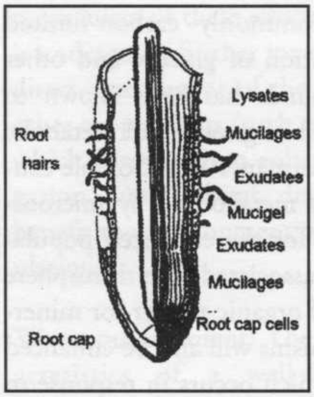

Figure 2. Cross-section of a root showing the general distribution of organic materials in the rhizosphere along the root segment.

Lysates - compounds produced as a consequence of bacterial activity breaking down epidermal cells
Exudates - simple organic compounds released from the plant cells
Mucigel - a complex of high molecular weight mucilages, microbial cells and clay particles
Mucilages - complex organic compounds released by plant cells or from bacterial activity
Root cap cells - released into the surroundings as the root grows; provide organic material for bacterial decomposition.

during normal plant development. Rhizodeposition of root exudates generally decreases with plant age, and increases under soil stresses such as compaction and low nutrient conditions.

The management of most turf systems produces a unique developmental environment in the soil ecosystem. Regular mowing to maintain a vegetative condition produces high levels of root turnover and new root production; as a result, it might be expected that continuing rhizodeposition will occur throughout the growing season.

Microbial Growth in the Rhizosphere

Population size and distribution are influenced by the carbon and energy sources available to microbes, as well as the amounts and availability of nitrogen, phosphorous and sulfur and a variety of naturally occurring growth factors. The mineralization of organic matter is a primary source of the carbon available for microbial growth. Non-specific population growth responses are related to organic matter mineralization. Evidence from the older scientific literature indicates that soil microorganisms are commonly carbon-limited (Newman 1978). Addition of glucose and other simple organic compounds has been shown to result in bursts of microbial growth and metabolic activity (Stotzky and Norman 1961). Soluble exudates which are readily metabolized by microorganisms likely account for the enhanced population sizes that are often associated with rhizosphere soils. The availability of organic matter for mineralization by microorganisms will also be enhanced by the root turnover which occurs in response to regular mowing of turf stands.

Parent (*Golf Course Management*, March 1996) considered the practical implications of carbon limitation in sand-based greens with respect to microbial population sizes. His experience suggests that supplementation with a carbohydrate (sugar)-based fertilizer can enhance the development of rhizosphere microbial populations; the interesting, but as yet scientifically substantiated observation, was that there appeared to be no disproportionate stimulation of possible plant pathogens.

This observation might reflect the ability of bacterial populations to access the sugar substrates more competitively than associated fungal pathogens in the system. The result might be a self-reinforcing feed back system in which enhanced bacterial populations contribute to better soil structure and nutrient turnover, thus improving conditions for both plant growth the development of beneficial microbial habitat.

Water availability is also critical to a healthy rhizosphere microbial population. Where water retention is low, soil microbial (particularly bacterial) activity is correspondingly low. This relationship might be especially critical since fungi can generally metabolize at lower water content than bacteria. Severe drying in the root zone profile might provide a competitive advantage to fungal rhizosphere organisms and increased potential for the development of localized dry spot, as well as enhanced fungal pathogen populations. Once again it is clear that the sand-based profile can create an environment that generates specific challenges for water and rhizosphere management.

Characterizing Microbial Populations

Historically, attempts to define microbial populations have been undertaken using microscopic evaluation of soil preparations, as well as the isolation and culture of microbes on artificial media. While microscopic analysis can provide some valuable evidence for bacterial and fungal biomass estimates, the procedures are not easily adapted for practical management. Culture techniques typically only sample a small fraction of the total population (<10%) which might not even be representative of the active microbial components. Functional activity in the rhizosphere is not necessarily linked to our ability to isolate and characterize individual species.

In the last decade considerable progress has been made in addressing the functional nature of soil microbial populations. Garland and Mills have used redox technology to assess community-based carbon source utilization characteristics of microbial populations. Analysis of the metabolism of 95 different carbon substrates has been used to provide a pattern of metabolic activity that appears to be characteristic of a particular microbial community. This Biolog™ technology couples microbial respiration with an easily measured and quantified dye color change. We have been working to develop an adaptation of the Biolog™ system to investigate microbial carbon use patterns in golf greens and other turf systems. Our preliminary results suggest that microbial populations vary with the season (not surprisingly), and in response to stress and management.

We are currently using this measurement technique to evaluate the establishment and early growth of 'Penncross' bentgrass on various amended sands receiving nitrogen supplementation from an inorganic vs. an organic source, and in the presence and absence of a carbohydrate supplement to stimulate the microbial populations. The strength of this measurement approach is that it is relatively rapid (3 days), does not depend on the ability to isolate and culture the microbes, and reflects the functional activity of the population rather than its growth characteristics. If the technique proves to be a reliable tool for rhizosphere evaluation, and particularly, if it can be used to predict rhizosphere health, it could become an essential feature of rhizosphere microbial management.

Managing the Microbes Can It Be Done ?

The biological and ecological fine points of rhizosphere plant-microbe interactions are clearly an interesting field for scientific study. However, are we any nearer transferring that knowledge and/or technology into the hands of the end user for active management ? I believe that we are.

I have repeatedly emphasized that amended sand greens begin life as a microbial wasteland, and that they do not provide a congenial habitat for healthy rhizosphere microbial growth and development. Management strategies should, therefore, be targeted at altering that imbalance to improve the rhizosphere environment as early as possible in the establishment of the turf.

Design changes: If the amended sand green is our currently accepted technology, what can we do to improve the rhizosphere habitat ? There are currently a number of inorganic amendments (e.g. zeolites, diatomaceous earth, calcined clays, pumice etc.) being used and tested in combination with sand to improve aeration porosity, as well as water and nutrient holding capacity in the sand. In addition to changes in the water and nutrient relationships, the exchange capacity binding sites and the pore spaces in materials such as zeolites might provide habitat potential for microbial development that is unavailable in the current amended sand mixes. Furthermore, in observations of demonstration trials on several golf greens in British Columbia, there is anecdotal evidence that zeolite-amended sand might confer some disease tolerance to the turf. Such observation is consistent with concept that the improved microbial habitat provided by the pore spaces creates enhanced microbial populations that contribute to a disease suppressive effect. We have also observed a direct inhibitory effect of zeolites on the growth of some fungal pathogens in laboratory tests. The mechanism of these effects remains unknown, but is undergoing further investigation. In addition to direct amendment of the sand profile, the use of other supplements (such as humic acid derivatives) which contribute to enhanced soil particle aggregation, and habitat development, might also benefit the development of healthy microbial populations.

Water management: The effective drainage characteristics of a well-designed sand profile encourage the regular use of water, particularly during the critical establishment and grow-in phases. As a result, sand-based turf often receives an abundance of water at intervals that are less conducive to the development of an extensive root system, or a stable rhizosphere microbial population. Shallow root growth is more likely to be associated with decreased stress tolerance and a rhizosphere microbial population which is smaller, less diverse and less resilient to environmental fluctuations. As Richard Hull noted in his earlier article (*Turfgrass Trends* February 1996) the plant response to soil drying is to divert photosynthetic resources to enhance root growth. Water management which can provide for mild drought stress between irrigations produces more deeply rooted turf with a greater potential for stress tolerance and a healthier rhizosphere microbiology.

Fertility management: The water and fertility management demanded to maintain a newly established amended sand turf is not conducive to rapid establishment of a stable root-microbe ecosystem. The use of amendments which can enhance nutrient and water holding capacity and contribute to improved microbial habitat will help to establish a vigorous efficient rhizosphere as soon as possible. Since there is no scientific basis to differentiate the nutrient "quality" of synthetic and organic fertilizers, the contribution of the latter class of product might be a function of the "non-nutrient" constituents and their influence on microbial populations. An extension of the idea that fertilization should include a strategy to address the rhizosphere microbial population has resulted in the generation of carbohydrate-based products specifically targeted at enhancing microbial growth. To date there is limited scientific evidence confirming the efficacy of such products. However, the philosophy underlying their development is consistent with an ecological perspective for effective turfgrass management - that improved microbial activity in the rhizosphere will enhance nutrient cycling, organic matter breakdown and improve soil structure. The enhanced soil ecosystem which is developed will support a healthier, more resilient turfgrass stand.

The turf management world is changing. Increased regulation, increased emphasis on "natural" turf management, and the continuing pressure to maintain turf quality make the professional manager's task a challenging one. Broadening the scope of our management attention to include the mysteries of rhizosphere microbiology will not ease the task, but it will become an increasingly significant component of the management of sustainable turfgrass ecosystems.

Dr. Brian Holl is a professor at the University of British Columbia in Vancouver, Canada. He has degrees in plant breeding, and biochemistry from the University of Manitoba, and in genetics from Cambridge University. Holl coordinates the Pacific Turfgrass Research Program and is involved in fine fescue breeding and research on plant-microbe interactions in the rhizosphere. He has been actively involved in the planning and development of the UBC Certificate in Turfgrass Management program.

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Glossary

Actinomycetes - Soil microorganisms intermediate between the bacteria and true fungi that normally produce a branched mycelium (hence the term "filamentous" bacteria).

Aerobic - Organisms or reactions that require the presence of oxygen in the atmosphere.

Anaerobic - Organisms or reactions that occur in the absence of oxygen.

Microaerophilic - Organisms or reactions that are adapted to low oxygen conditions (but do not function in aerobic or anaerobic environments).

Mycelium - Stringlike filaments of cells characteristic of the growth pattern of the true fungi and actinomycetes. These filaments (hyphae) might be branched or unbranched.

Redox technology - Redox reactions refer collectively to metabolic processes that involve reduction and oxidation (transfer of electrons) - common elements of respiration. These reactions are easily linked to compounds which change color when oxidized or reduced and are convenient ways to measure respiration as a reflection of metabolic activity in environmental samples.

Rhizodeposition - The release and deposit of a variety of carbon compounds and root cell residues along the surface of the developing root, and into the adjacent soil environment.

Strategies for Insect Control

Patricia J. Vittum
University of Massachusetts

Turf managers have been under increasing pressure to reduce their reliance on pesticides. Fortunately there are several alternatives which have been developed in recent years which can be incorporated into a turf management scheme which will reduce the insect pressure or perhaps reduce the stress under which the turf is growing. Normally this results in a decrease in damage caused by pest insects. However, such a management scheme is more complicated or involved than the old "spray and pray" approach, and turf managers must be much more knowledgeable about many more aspects of their turf and the environment surrounding the turf. The following are steps to maximizing the chances for success in managing turf insects.

Identifying the Pest

Most turf managers are familiar with the most common turf pests and can recognize many of them. Some turf insects resemble others but have very different life cycles. Insecticide applications directed toward one probably would not be effective against the other.

For examples, there are many different species of white grubs. The European chafer normally begins to lay eggs about two weeks earlier than Japanese beetles in a given location. In many parts of the country, May beetles have a two or three year life cycle and insecticide applications are only effective during a few fairly brief stretches during that time.

Thresholds of Tolerance

Turf is able to tolerate one or two stresses (low mowing height, nutrient deficiency or too much water) but begins to show visible signs of distress when additional stresses are added. In many cases a small population of insects is present in a stand of healthy, vigorous turf without evidence because the turf is not under other stresses and can outgrow the damage caused by the insects. But the same population of insects in grass which is already under stress could cause visible damage, because the grass is unable to respond quickly enough to mask the insect activity.

One golf course where I have conducted much of my work averaged 30 to 35 Japanese beetle grubs per square foot without showing any signs of weakness. Roots remained healthy and vigorous and the turf did not appear to be in drought stress. That golf course has a virtually unlimited water supply and relatively few rounds of golf per year. In contrast, a nearby public golf course has a limited water supply with 90,000 rounds of golf per year. That golf course experiences noticeable damage (torn up turf, pruned root systems) with as few as 5 grubs per square foot.

The challenge for a turf manager is to begin to determine the tolerance levels (how many insects is too many?) for insects in the turf areas being maintained. The main point to remember is that **tolerance levels are site specific and vary throughout the growing season.**

Several things must be taken into consideration when trying to establish tolerance levels. The **recuperative potential** of the turf varies during the growing season because of seasonal stresses. For example, when the availability of irrigation is limited and turf is under moisture stress, turf is less able to tolerate feeding activity from insects. Similarly if an area has been weakened by disease activity, it will be more vulnerable to insect or weed infestation.

The **species of insect** is often critical. For example, grub for grub, European chafers tend to be more damaging than Japanese beetles, in part because the European chafer is a larger species. In addition, European chafer grubs actively feed in the root zone later in the autumn and return to the root zone earlier in the spring, a longer period than other grubs. Cricket for cricket, tawny mole crickets often are more damaging than southern mole crickets, in part because tawny mole crickets feed directly on turf roots while southern mole crickets feed primarily on other insects.

Another factor which is sometimes overlooked when setting tolerance levels is the **expectations of the customer**. Most turf managers maintain turf for some specific purpose (golf course, athletic field, playground, or home lawn). In each case the "customer" has certain perceptions of what turf should look like. For example, many golfers expect (and virtually demand) nearly perfect conditions on putting greens and would not tolerate any visible evidence of insect activity. The same golfers normally don't expect the same level of perfection in the rough.

Levels of maintenance vary greatly, depending in part on the **budget** of the operation. Tolerance for insect activity will be lower in a highly maintained athletic field. Insect damage often goes unnoticed in a low-budget field.

Finally, sometimes there are excellent "curative" insecticides available for a given insect problem - materials that can be applied after a damaging population develops but still can kill enough of the immature insects to reduce the population back below tolerance levels. A turf manager can delay the treatment decision longer and treat only those areas that are attacked. Unfortunately, when there are no adequate curative insecticides, applications must be made before the insect population has developed fully.

Understanding the Life Cycle

The main reason to set thresholds or tolerance levels is to determine whether a given pest population must be managed (reduced). **All management strategies rely on a solid understanding of the life cycle.** As insects grow and molt, they pass through certain periods of their lives during which they are more vulnerable than others. The key to successful management is targeting the population when most of the individuals are in the most vulnerable stage.

Most insects are particularly susceptible to traditional insecticides when they have just hatched out of the egg. Conversely, the egg and pupa stages essentially are not susceptible to insecticides. So many turf insecticides are most effective when directed toward the insects when they are small larvae or nymphs. (Note that a few turf insect pests, such as annual bluegrass weevils, bluegrass billbugs, and black turfgrass ataenius, are vulnerable in the adult stage and insecticide applications often are directed at that stage.)

Several excellent references are available which outline the basic life cycles of the major turf insect pests, but local conditions can result in significant variations. A turf manager must be aware of those local differences and have a clear understanding of when the adults will be active, when eggs will be laid, and when the immatures (larvae or nymphs) are likely to begin hatching. **The most important aspect of insect management with insecticides is timing of application**, and the optimum timing of application can only occur when the life cycle and local conditions are understood.

Cultural management strategies

In recent years several turfgrass cultivars have been developed which are resistant to particular turf insects. The most notable example is cultivars which contain **endophytes**, fungi that grow within the turf plant and produce materials which are toxic to certain insects. Endophytic cultivars, available in perennial ryegrasses and some of the fescues, can significantly reduce the survival or population density of bluegrass billbugs, hairy chinchbugs, and some webworms. Turf managers who experience damage from these insects and are planning on renovating turf areas should consider using endophytic cultivars whenever possible.

Other forms of plant resistance have been identified and commercialized. Some cultivars of St. Augustinegrass have shown resistance to the southern chinch bug. Some cultivars of Kentucky bluegrass appear to be resistant to billbugs.

Many turf insects have specific grasses which they prefer to attack (for example, ryegrasses and fescues for hairy chinch bugs, St. Augustinegrass for southern chinch bugs, annual bluegrass for annual bluegrass weevils, bermudagrass and bahiagrass for mole crickets, Kentucky bluegrass and fescues for billbugs). A turf manager can renovate an area to reduce the prevalence of a preferred grass and incorporate a less preferred host instead.

Damage from many turf insects is often most severe when it occurs on turf under drought stress. For example, hairy chinch bug activity is greatest on turf growing on sandy (well drained) soils and exposed to sunlight - precisely the conditions which lead to drought stress. Sometimes the simple act of irrigating the vulnerable area enables the turf to recover from insect activity.

If good cultural management practices are followed, turfgrass often can tolerate insect activity without showing damage. **Fertilizer** schedules should reflect the seasonal needs of the plant as well as the specific nutritional requirements. **Raising mowing heights** often reduces stress ("the higher the shoot, the healthier the root") and enables turf to outgrow insect activity. Managing **traffic patterns** to avoid compaction also can reduce stress. **Syringing**, to avoid extremely high temperatures, is another cultural practice which can improve the overall vigor of the turf.

Biological Control Options

There are several biological pesticides available commercially for use on turf. Most of these either bacteria or nematodes which cause disease in certain insects. Many of these biological agents are relatively specific, and thus are unlikely to interfere with the many beneficial insects and other arthropods which occur in turf.

Bacillus thuringiensis (BT) is a bacterium that produces a toxin that paralyzes the digestive system in a target insect. There are several strains of BT, each of which is fairly specific and effects only a limited number of insects.

The "kurstaki" strain is effective against several kinds of caterpillars, including cutworms and webworms, and is available in formulations which are sprayed through traditional hydraulic sprayers. BT is less effective against large caterpillars, so it should be applied when caterpillars are still relatively small.

Entomopathogenic nematodes are small round worms which cause diseases in insects. Several species have been identified and at least three are available commercially. Most of these nematodes are sensitive to desiccation so applications should be made early in the morning or late in the afternoon and should be watered in immediately. *Steinernema carpocapsae* is effective against some caterpillars, and there is evidence that it could be effective against some species of billbugs. Field tests by several researchers suggest that this nematode is not effective against white grubs.

Steinernema riobravis and *Steinernema scapterisci* are two species which are effective against mole crickets. It appears that adult mole crickets are more susceptible to attack than smaller mole crickets, probably because the nematode must find a natural opening large enough to wriggle through to get into the host mole cricket. Field collection of mole crickets suggests that southern mole crickets might be more susceptible to attack than tawny mole crickets.

Researchers are investigating other kinds of biological control, including parasitic wasps and flies and predatory insects. For example, research is underway to determine whether a parasitic wasp which originated in South America can have a measurable effect on annual bluegrass weevils in field conditions. A tachinid fly which also originated in South America has been released in Florida to reduce mole cricket populations, and has become established in several locations.

Chemical Control Options

While cultural management and biological control options exist for many turf insects, the level of expectation of the customer often dictates that a turf manager will have to consider using traditional insecticides to maintain pest populations below tolerance levels.

Windows of Opportunity - Each insect has a period during its life cycle when it is most susceptible to insecticides. Normally this is when the insects have just hatched from eggs to small larvae or nymphs. Some insects and mites (e.g. bermudagrass mite) are only in the vulnerable stage for a short period of time. In such a situation, the material must be a reasonably fast acting product. The key to success is **timing of application**.

Other insects spend more time in the vulnerable stage, so the "window of opportunity" is longer. For insects which complete more than one generation per year, there is often a time during the growing season when all stages (adults, eggs, immatures, and pupae) can be found in a given location. Timing of insecticide applications in this situation seems more complicated. The turf manager must determine when **most** of the insects are most vulnerable and then take action. In some cases, more than one application will be necessary, because the first one will not affect the individuals which were eggs at the time the material was applied.

For many of the **cutworm** species which attack turf, adult flight can be an excellent indicator of the ideal time to apply an insecticide. Guidelines from state specialists usually recommend applying an insecticide 10-21 days after peak adult (moth) flights are observed. (The precise timing depends on the species of cutworm and the local weather conditions.) The peak flight occurs just as females begin to lay eggs, and time should be allowed for those eggs to hatch into caterpillars before an insecticide is applied.

The timing of application for **white grubs** depends in part on the kind of insecticide. White grubs hatch from eggs any time from early July through late August in the Northeast, depending on winter and spring conditions (cool spring temperatures delay beetle flight and egg hatch), species, and soil moisture. So the "window of opportunity" is relatively broad - from late July to early September.

Some insecticides (e.g., Proxol™ or Dylox™) are active against grubs within a few days after they are applied, but break down quickly. Such materials should be used **late** in the "window of opportunity" after most of the grubs have hatched out of eggs but before the early hatchers have begun to cause visible damage. Other insecticides (e.g. Oftanol™) take 10 to 14 days before they are active against grubs, but remain active for several weeks. Such materials should be used **early** in the "window of opportunity" before some of the individuals have hatched from eggs. This is because the turf manager risks incurring some damage if he or she delays the application too long. The longer residual activity of these materials ensures that the material will be active when the late hatchers emerge. If the application is delayed and made late in the "window of opportunity", many of the grubs will already be large enough to cause significant damage before they are killed by the relatively slow material. Most other insecticides on the turf market for grubs are somewhat intermediate - they become active within three to seven days after they are applied and remain active for three to six weeks.

Merit™ should be discussed separately because its use pattern is much different than that of any other insecticide currently available for grub control. Merit™ seems to be effective for at least ten weeks after application (and often considerably longer), so it can be applied to an area in which a damaging grub population is expected long before the grub activity begins. Applications made in May normally remain active against subsequent white grub infestations three or four months later. Such an application is well outside the "window of opportunity" but fits well into the scheduling needs of many turf managers. Note, however, that most turf specialisits do not recommend that any single material (whether Merit™ or something else) be used more than two years in a row in a given location, primarily to reduce the chance of resistance by the insect population.

The timing of emergence of **mole crickets** varies widely from North Carolina to southern Florida, where they often complete two generations per year. So generalizations about timing of applications for mole crickets are risky at best. A good approach is to use soapy flushes to determine when small nymphs begin to hatch (often June or July in the Gulf States). Any adults which are flushed to the surface (or are attracted to lights at night or caught in pitfall traps) can be inspected for their reproductive development. When females are about ready to lay eggs, those eggs can be exposed by a careful inspection of the contents of the abdomen. When a significant percent of the females inspected have well developed eggs, soapy flushes should be conducted at least twice a week. As soon as small nymphs are found in the flushes, an insecticide application should be contemplated - at least in areas where the populations exceed the tolerance level.

Soil Insects - Soil insects are often more difficult to manage than surface feeders for several reasons. The insects are "out of sight and out of mind," so sometimes damaging populations develop before a turf manager realizes the insects are present. Because the insects spend much of their time below the thatch, it is more difficult to achieve good contact with an insecticide. Most insecticides are bound to some degree by thatch and much of the active ingredient does not reach the soil/thatch interface where grubs or mole crickets are active.

One of the critical steps in obtaining good control of soil insects like white grubs is to irrigate the treated area immediately after application or apply just before a steady rainfall. The water helps to move some of the active ingredient partway through the thatch, and also induces the grubs to move further into the thatch to take advantage of the improved moisture conditions. The end result is greatly enhanced insecticide/grub contact.

When the soil is unusually dry during the summer and there is barely enough moisture to keep the turf above the wilting point, grubs, mole crickets, and other soil insects often move downward in the soil profile. Some species of white grubs can move vertically as much as 24 inches in 24 hours. Not surprisingly, in these circumstances grubs are much too deep to be affected by any insecticide application made on the surface. The effectiveness of an application can be improved significantly by irrigating the area 24 to 36 hours BEFORE the intended application and irrigating again immediately after the application. Pre-watering increases soil moisture near the surface and induces the grubs to return to the root zone, where they come in contact with the insecticide.

Several field studies have suggested that different formulations of the same active ingredient are equally effective against white grubs. As a rule of thumb, most granular formulations will take a little longer to become active than sprayable formulations of the same active ingredient, but they also will remain active a little longer. So the ultimate choice of a formulation, at least for white grubs, depends on other considerations such as cost, needs and availability of storage space, application equipment, and perceptions of the customer. (Note that many homeowners still seem to think that a granular product is "safer" than a sprayable material.)

Sub-Surface Applications - Sub-surface application is a relatively new application technology that can enhance the performance of insecticides against soil insects. The concept is simple - if an insecticide can be placed directly at the soil/thatch interface, where white grubs and mole crickets tend to be most active, it should be much more effective than a traditional surface application.

One sub-surface technology uses **high pressure liquid injection** to drive sprayable formulations through the thatch. Some equipment uses pulsed injection, similar to that used with the Toro Hydroject liquid aerifier, and generates pressures up to 5,000 pounds per square inch. Other equipment uses steady (constant) stream injection, with a range of pressures up to 4,000 pounds per square inch.

Each system uses nozzles with tiny orifices placed on a drag bar which travels on the ground and directs the spray straight into the turf. The depth of penetration depends on the orifice size (smaller openings normally lead to greater penetration), pressure, ground speed, and density and thickness of thatch. The main concern is to avoid the temptation to "crank the unit up" and deliver the insecticide below the soil/thatch interface. Most high pressure units merely dent the turf so the surface is playable immediately after the application has been completed.

Another sub-surface technology uses slicing to produce slits in the turf, into which granular or liquid formulations can be deposited. These units vary widely, with many different techniques for cutting the slit and pulling the turf back over the slit as the unit passes. Some units are quite "tidy" and leave little evidence after the application, while others are quite disruptive to the turf surface. Sub-surface slicing does not have the inherit risks associated with high pressure injection (e.g., bursting hoses) Adjusting the depth of penetration is usually simple. In addition, slicing enables a turf manager to apply virtually any insecticide, regardless of formulation, and opens up opportunities to apply some of the biopesticides (bacteria, nematodes) that would benefit by being placed directly at the soil/thatch interface. Entomopathogenic nematodes which are applied through a high pressure injection system are not recognizable, and certainly are not viable, when they emerge from the business end of the unit!

Field trials conducted throughout the country (Dr. Pat Cobb in Alabama, Dr. Fred Baxendale in Nebraska, Dr. Dave Shetlar in Ohio, Dr. Pat Vittum in Massachusetts, among others) have demonstrated that sub-surface application has numerous advantages:

1. In some instances, the rate of application can be reduced (up to 50%) compared to surface application without any reduction in the level of control.
2. Surface residues of most insecticides are reduced 50 to 80% when applied sub-surface (Vittum, unpublished data).
3. The material is placed below the surface, so it is not broken down by sunlight as rapidly as a surface application.
4. The likelihood for run-off is reduced.
5. Some materials, such as fipronil (Chipco Choice™), are registered for use only when applied sub-surface.

One of the drawbacks of sub-surface application is that the current equipment is very specific and cannot be used for anything but sub-surface applications. Therefore, the equipment must be dedicated to a limited number of jobs (perhaps application of insecticides against soil insects, some fertilizer applications) and might not be cost effective for most turf managers. In the Southeast, a few companies have bought equipment and made sub-surface applications on a contract basis. The same approach has been initiated in the Northeast but has not been embraced nearly as widely yet.

Surface and Thatch Insects - While turf managers notice surface insects (cutworms, webworms, armyworms, bermudagrass mites) or thatch insects (chinch bugs, billbugs, leather jackets) more quickly than soil insects, managing them can still be challenging. Some of these insects have shorter development times and can complete several generations per year, particularly in warmer regions of the United States. As a result, populations can build up rapidly. Generations often overlap so that some individuals are in susceptible stages (small larvae or nymphs) while others are not vulnerable (eggs or pupae). This overlap makes it very difficult to time insecticide applications because there often is a substantial portion of the population in a non-vulnerable stage. Turf managers must try to determine when the majority of the population will be in a vulnerable stage and time an application accordingly.

For most surface and thatch insects, an insecticide application should not be watered in very heavily, but some water should be applied (either through irrigation or rain) shortly after the application to move the material off the tips of the grass blades and into the thatch. As with any insecticide application, check the pH of the water in the tank and use an additive if the pH is higher than 8 to guard against alkaline hydrolysis.

Some insecticides (e.g., Dursban™) are bound in the thatch more readily than others. While such insecticides usually are not appropriate against soil insects (because the material never gets to the soil), they are often excellent materials to use against surface and thatch feeders because they stay in the thatch, precisely where the target insects are. Some insecticides (e.g., Proxol™ or Dylox™) are highly soluble and pass through the thatch much more quickly than others. Such materials would not be as desirable for control of thatch insects because they move through the target zone too quickly.

The **formulation** of an active ingredient may play a greater role in determining the effectiveness of an insecticide when the material is directed toward surface or thatch feeders. Some researchers believe that pre-watering an area, applying a granular product, and then lightly watering the area will provide good coverage, and that the "bulk" of the granule helps to keep the active ingredient in the target zone. Others believe that sprayable formulations are more likely to achieve good contact with the blades and stems and provide a better level of control. Field trials appear to be inconclusive.

Final Thoughts

Even though turf managers are always trying to provide optimum growing conditions for the turf, that effort must be increased if an insect population approaches the level that will cause damage. While there are several biological control options available commercially and more under development, most managers of highly maintained turf still must rely on traditional insecticides to reduce insect populations. The main key to successful management of those populations is **TIMING** - an application must be made when the bulk of the population is vulnerable, or else the manager is wasting time and money.

The rest - selecting a suitable insecticide (speed of action, residual activity, movement in thatch, chemical class, formulation), deciding on a method of application (traditional surface application or new subsurface application), and arranging for pre- or post- application water - is, to a certain extent, peripheral.

So build up that reference library and start keeping files of information on different insects so you know what to expect - and when you should be prepared to take action.

***Dr. Patricia J. Vittum** is an associate professor in the Department of Entomology at the University of Massachusetts, Amherst. She has a B.A. in chemistry from the College of Wooster (Ohio) and a M.S. and Ph.D. in entomology from Cornell University.*

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