POTENTIAL FOR BIOLOGICAL CONTROL OF TURF DISEASES

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INTRODUCTION

Disease management represents a significant challenge for turfgrass managers. This is made particularly demanding by the perennial nature of turfgrass plantings as well as that of the disease-causing organisms. Since most, if not all, of the fungal pathogens of turfgrass are always present in turfgrass plantings, rarely is the pathogen's presence or population level limiting for disease development. As a result, the principal factors determining the incidence and severity of turfgrass diseases are environmental factors and plant stresses that influence not only the activity of pathogens, but the susceptibility of turfgrass plants. This is particularly true for some root pathogens for which turfgrass plants remain infected year round. Since in many cases these factors cannot be manipulated adequately to minimize losses from fungal diseases. Turfgrass managers rely on applications of fungicides for the management of fungal diseases.

Of the fungicides being used for turfgrass disease control, most are broad-spectrum systemic fungicides. Many problems have arisen from the repeated and prolonged use of such chemicals. Included among these is the development of fungicide-resistant pathogen populations, deleterious effects on non-target organisms, particularly those involved in carbon and nitrogen cycling, enhancement of non-target diseases and the selection of fungicide degrading microorganisms. In an effort to reduce this fungicide dependency and to prevent many of the undesirable biological and environmental effects of excessive fungicide use, alternative management practices are being explored.

One of more exciting alternative management strategies being developed is the use of biological controls in which individual or mixtures of microorganisms are deployed to reduce either the activities of pathogens or enhance the tolerance of plants to disease. This approach to disease control has been used successfully on an experimental as well as a commercial basis for the control of plant pathogens on several crop plant species.

APPROACHES TO BIOLOGICAL CONTROL

Most turfgrass managers are familiar with the negative aspects of soil microorganisms since many are pathogenic and can damage a turfgrass stand. However, in addition to pathogens, the soil harbors a variety of non-pathogenic microorganisms that actually improve plant health. These soil bacteria and fungi are responsible for increasing the availability of plant nutrients and forming symbiotic associations with turfgrass roots, for producing substances stimulatory to plant growth, and for protecting plants against infection from pathogenic fungi.

The practice of biological control attempts to take advantage of all of the above-mentioned microbial attributes in order to minimize damage from plant pathogens. For example, the application of composts or other well-decomposed sources of organic matter to turf may introduce large populations of antagonistic microorganisms which may reduce disease by interfering with the activities of pathogenic fungi. Similarly, cultural management techniques such as core aeration or the application of lime, may reduce disease development by altering the soil and thatch microbial communities within which pathogens must function. In such cases, cultural practices may indirectly affect disease severity by changing the environment to favor the antagonistic microflora to the detriment of the pathogen population.

Biological control may be achieved either through the application of introduced antagonists or through the manipulation of native antagonists present in disease-suppresive soils and on plant parts. In either case, the goal is to reduce or eliminate pathogen activities either by reducing pathogen inoculum in soil, protecting plant surfaces from infection, or by inducing natural defense mechanisms within the plant.

Biological control of pathogen inoculum may occur by the microbial destruction of pathogen propagules and the prevention of inoculum formation through the action of mycoparasites (i.e., fungi parasitic on other fungi). In addition, antibiotic-producing antagonists may displace pathogens in decaying plant residues such as thatch and reduce their populations in soil. Many non-pathogenic soil microorganisms are able to effectively colonize above-ground as well as below-ground plant parts and in so doing, protect these tissues from infection by pathogens. It is also apparent that some biological control agents can induce natural defense mechanisms in plants; a phenomenon referred to as cross protection or induced resistance.

Some of the more commonly studied antagonists include fungi in the genera *Fusarium, Gliocladium, Laetisaria, Penicillium, Sporidesmium, Talaromyces, Trichoderma* and *Verticillium* and bacteria in the genera *Bacillus, Enterobacter Erwinia* and *Pseudomonas*. Research has shown that these microorganisms can interfere with pathogen populations in a number of ways. Mycoparasites such as *Trichoderma* and *Sporidesmium* may parasitize pathogen propagules and mycelium. Other antagonists, particularly *Pseudomonas, Bacillus, Enterobacter, Erwinia* and *Gliocladium* produce antibiotics inhibitory to pathogen growth. Some strains of *Pseudomonas* and *Enterobacter* species can out-compete pathogens for essential nutrients and other growth factors, thereby reducing pathogen germination, growth and plant infection.

Antagonists of turfgrass pathogens can be found in a variety of sites. They are particularly abundant in turfgrass soils and thatch as well as in decaying organic substrates. In a recent study, a greater percentage of Pythium blight antagonists were found associated with thatch that with the rhizosphere soil of turfgrasses in both low and high maintenance sites. However, those associated with thatch were generally more effective in suppressing the disease. Among the bacteria screened, those members of the Enterobacteriaceae were significantly more efficaceous than other general heterotrophic bacteria and *Pseudomonas* species.

In order to predictably and successfully manipulate biological control agents, their biology and ecology in turfgrass ecosystems must be understood. Biological control agents differ fundamentally from chemical fungicides in that they must grow and proliferate to be effective. Therefore, effective antagonists must be able to establish and survive in turfgrass ecosystems and remain active against target pathogens during periods favorable for plant infection. The two factors most important in determining how well antagonists will establish and grow are 1) the environmental conditions, particularly temperature, moisture, nutrients, and pH and 2) their ability to compete with the existing soil and plant microflora. Just as some organisms are antagonists of pathogens, antagonists have their own antagonists as well.

Biological control agents must also be compatible with other management inputs. In particular, biological control agents must be tolerant of fungicides, insecticides, herbicides and fertilizers currently used in management programs. Their activities must also not be discouraged by cultural practices used in turfgrass maintenance. Just as pathogens are influenced by environmental conditions, so too are biological control agents. Therefore, biological control strategies must be employed primarily to control the pathogen, but at the same time, maintain the associated antagonistic microflora.

Although few in-depth studies on the biological control of turfgrass diseases have been conducted, promising results have been obtained using complex mixtures of microorganisms and individual antagonists as tools for managing fungal diseases of golf course turf (Table 1). While individual organisms isolated from many different environments can be suitable for use as biological control agents, composts and organic fertilizers are perhaps the best sources of complex mixtures of antagonistic microorganisms.

Table 1. Known examples of turfgrass disease biological control

Disease (*pathogen*)	Antagonists	Location
Brown Patch	*Rhizoctonia* spp.	Ontario Canada
(*Rhizoctonia solani*)	*Laetisaria* spp.	N. Carolina
	Complex mixtures	New York, Maryland
Dollar Spot	*Enterobacter cloacae*	New York
(*Sclerotinia homoeocarpa*)	*Fusarium heterosporum*	Ontario Canada
	Gliocladium virens	South Carolina
	Complex mixtures	New York
Pythium Blight	*Pseudomonas* spp	Illinois, Ohio
(*Pythium aphanidermatum*)	*Trichoderma* spp.	Ohio
	Trichoderma hamatum	Colorado
	Enterobacter cloacae	New York
	Various bacteria	New York, Pennsylvania
	Complex mixtures	Pennsylvania
Pythium Root Rot	*Enterobacter cloacae*	New York
(*Pythium graminicola*)	Complex mixtures	New York
Red Thread	Complex mixtures	New York
(*Laetisaria fuciformis*)		
Southern Blight	*Trichoderma harzianum*	N. Carolina
(*Sclerotium rolfsii*)		
Take-All Patch	*Pseudomonas* spp.	Colorado
(*Gaeumannomyces graminis*	*Gaeumannomyces* spp.	Australia
var. *avenae*)	*Phialophora radicicola*	Australia
	Complex mixtures	Australia
Typhula blight	*Typhula phacorrhiza*	Ontario Canada
(*Typhula* spp.)	*Trichoderma* spp.	Massachusetts
	Complex mixtures	New York

THE USE OF COMPOSTS FOR BIOLOGICAL DISEASE CONTROL

In order to re-establish the microbiological balance of soils on which intensively managed turfgrasses are grown, sufficient organic matter must be introduced into the soil/plant system to support microbial growth and activity. Some of the best sources of both organic matter and populations of antagonistic microorganisms are composted materials. Fortunately, composts are currently available, in many cases at no charge, and they can be applied as a top-dressing without the need for elaborate and expensive equipment. Golf greens and tees are top-dressed several times a season with a mixture of sand and some type of organic matter (usually peat) or soil. Most sphagnum peats used in topdressings, however, have little or no disease-suppressive properties. It should be relatively easy, therefore, to replace the peat with composted manures, sludges, and/or food and agricultural wastes that are readily available and inherently disease-suppressive.

A. The Composting Process

Composting has been defined as the "biological decomposition of organic constituents in wastes under controlled conditions." Since composting relies exclusively on microorganisms to decompose the organic matter, the process has biological as well as physical limitations. During composting, the environmental parameters (i.e., moisture, temperature, aeration) must be stringently controlled. This is necessary to maintain adequate rates of decomposition and to avoid the production of decomposition by-products that may be harmful to plant growth. In order to maintain proper temperatures, the composting mass must be large enough to be self-insulating but not so large that compaction results in reduced air exchange. The composting mass must be moist enough to support microbial activity but not excessively moist so that air exchange is limited. The particle size of the material must be small enough to provide proper insulation but not too small to limit air exchange.

Composting involves successions of both mesophilic (moderate-temperature) and thermophilic (high-temperature) microorganisms during various phases of organic matter decomposition. Each microbial community makes an important contribution to the nature of the composted material. Failure to maintain environmental conditions favorable for adequate microbial activity could jeopardize the quality of the final product.

When all of the environmental and physical conditions are optimized, composting should proceed through three distinct phases. During the initial phase lasting one to several days, depending on the type of starting material, temperatures in the internal portions of the composting mass rise as a result of the growth and activity of the indigenous mesophilic microorganisms associated with the starting organic material. During this self-heating phase, most of the soluble, readily degradable materials are broken down by these naturally-occurring microorganisms, precluding the need for additional inoculum. At this stage of composting, populations of microorganisms increase in size and activity.

As temperatures increase above 40°C, the mesophilic populations are replaced by thermophilic populations that are capable of degrading most of the resistant polymers such as cellulose and hemicellulose. During this stage of decomposition, microbial diversity decreases and only on of several species of *Bacillus* are active in decomposition processes. The thermophilic phase may last several months, depending on the cellulose content of the material and the temperatures maintained during this period. Generally, the higher the cellulose content, the longer the thermophilic phase. Temperatures required for thermophilic decomposition rage from 35 - 70°C. However, the highest rate of microbial activity and decomposition occurs at the lower end of the thermophilic range at temperatures of 35 - 55°C. Increase in temperature above 55°C can be self-limiting to the decomposition process. To overcome these constraints, most composts need to be aerated either through repeated pile inversions or through forced air ventilation. Prior to placing in windrows, many composts are started in aerated vessel systems where temperatures can be precisely regulated and uniform decomposition can be established.

Since composting consumes much oxygen, aeration serves to keep the composting mass aerobic instead of anaerobic. Should composts become anaerobic, many toxic microbial metabolites can accumulate resulting in detrimental effects on plants coming in contact with such material.

Additionally, undesirable odors are present in uncontrolled anaerobic composts. Most composts produced in a proper aerobic environment should have little or no odor associated with the decomposing mass. Aeration also serves as a means of drying the material, making it more suitable for handling and transport.

As the cellulose and hemicellulose components are exhausted, the compost enters a curing or stabilization phase where temperatures decline, decomposition rates decrease and the thermophilic microbial populations are again replaced by mesophilic populations. In general, the longer the curing period, the more diverse the colonizing mesophilic microflora. It is this recolonizing mesophilic microflora that is most important in suppressing turfgrass diseases since a large proportion of the recolonizing mesophilic microflora is composed of microbial antagonists that render the compost disease-suppressive. Unfortunately, there is no reliable way to predict the disease-suppressive properties of composts since the nature of the recolonizing antagonist population is left to chance and will be determined largely by the microflora present at the composting site.

B. Disease Suppression with Composts

Applications of composted materials can suppress turfgrass diseases. Monthly applications of top-dressings composed of as little as 10 lbs of suppressive compost/1000ft^2 are effective in suppressing diseases such as dollar spot, brown patch, Pythium root rot, Typhula blight and red thread (Table 2). Reductions in severity of Pythium blight, summer patch and necrotic ringspot have also been observed in sites receiving periodic applications of composts. Of particular benefit is the impact of prolonged compost applications on root-rotting pathogens in soil. Populations of soilborne *Pythium* species are generally not suppressed following traditional chemical fungicide applications, but can be reduced on putting greens receiving continuous compost applications in the absence of any chemical fungicide applications. Additionally, heavy applications of composts (~200 lbs/1000ft^2) to putting greens in late fall are effective not only in suppressing winter diseases such as Typhula blight, but in protecting putting surfaces from winter ice and freezing damage.

Composts prepared from different starting materials as well as those at different stages of decomposition vary in the level of disease-suppression and in the spectrum of diseases that are controlled (Table 2). This is primarily a result of the microbial variability among different composts and among the different qualities of organic matter present in any one compost at various stages of decomposition. Although microbial activity is necessary for disease-suppressive properties to be expressed in most composts, the specific nature of disease suppressiveness is, in general, unknown.

The microbiology of disease-suppressive composts has not been extensively studied. Fungal and bacterial antagonists have been described from hardwood bark and sewage sludge composts suppressive to a number of plant pathogens. Relationships between microbial activity and *Pythium* suppression in composts have also been described. Nelson *et al.* found *Trichoderma hamatum, T. harzianum* and *Gliocladium virens* from suppressive bark composts to be the most important fungi in the suppression of *R. solani*, whereas Kwok *et al.* identified a number of bacterial species effective against *R. solani* in bark composts. However, strains of *Enterobacter cloacae, Flavobacterium balustinum, Xanthomonas maltophila* and various fluorescent *Pseudomonas* spp. were more effective in suppressing *R. solani* when combined with an isolate of *Trichoderma hamatum*.

Antagonists of other plant pathogens have been studied in less detail. Various oligotrophic *Pseudomonas* species from composts are effective root colonists and antagonists of *Pythium ultimum*. In some sewage sludge composts, thermophilic strains of *Bacillus subtilis* are effective in inducing suppression to a number of soilborne plant pathogens.

Although a wide variety of microbial antagonists can be found in composted substrates, the predominant species and their relative contributions to disease suppression remain unknown. However, those microorganisms that are rapid and aggressive colonizers of organic matter are more likely to contribute the most to disease suppression in composts.

C. The Need for Predictably Suppressive Composts

The use of top-dressings amended with disease-suppressive composts or organic fertilizers is being accepted by turfgrass managers as an attractive disease control alternative. In the few cases that have been examined, substantial reductions in fungicide use have accompanied the adoption of these strategies. Many composted materials and other organic fertilizers are commercially available and can be found in many garden centers. Others are available from municipal waste treatment facilities. Research has shown that the use of composts and organic fertilizers for turfgrass disease control is economically and technologically practical and, in some instances, can provide levels of control as good as that currently attained with fungicides.

Table 2. Turfgrass Diseases for which Composts have been Suppressive

Disease (*pathogen*)	Mode of Application	Turfgrasses
Brown Patch (*Rhizoctonia solani*)	top-dressings	Creeping Bentgrass/Annual Bluegrass
Dollar Spot (*Sclerotinia homoeocarpa*)	top-dressings	Creeping Bentgrass/Annual Bluegrass
Necrotic Ringspot (*Leptosphaeria korrae*)	top-dressings	Kentucky bluegrass
Pythium Blight (*Pythium aphanidermatum*)	top-dressings[b]	Perennial Ryegrass
Pythium root rot (*Pythium graminicola*)	top-dressings and heavy fall applications	Creeping Bentgrass/Annual Bluegrass
Red Thread (*Laetisaria fuciformis*)	top-dressings	Perennial Ryegrass
Summer Patch (*Magneporthe poae*)	top-dressings	Kentucky bluegrass
Typhula blight (*Typhula* spp.)	heavy fall applications[a]	Creeping Bentgrass/Annual Bluegrass

[a] Applied at the rate of ~200 lbs/1000 ft^2.

[b] Applied at the rate of ~10 lbs/1000 ft^2.

One of the principal problems associated with the use of composts for disease control is that a given compost may not be predictably suppressive from year to year, batch to batch, and from one site to the next. Turfgrass managers and compost producers agree that the future success of these materials in commercial turfgrass management depends upon the abilities of producers to provide material with predictable levels of disease control. Gross variations in disease-suppressive qualities of composts cannot be tolerated because end-users need to be assured that every batch of compost used specifically for disease control will work every time. Unfortunately, we do not yet know how to predict the suppressive activity of certain composts without actually testing them in field situations.

A number of assays have been developed to determine compost maturity and degree of stabilization for the purpose of reducing the variability in physical and chemical properties. However, none have been designed to directly assess microbiological aspects of maturity and disease suppressiveness. As composts decompose and mature, changes in the quality of the organic matter are apparent. During composting the levels of carbohydrates decrease while the level of aromatic carbon compounds increases. Readily available carbon compounds and cellulose can support the activities of plant pathogens such as *Pythium* and *Rhizoctonia*. However, as these compounds are reduced during composting, saprophytic growth of such pathogens is dramatically reduced. Antagonists also are affected by these changes in organic matter quality. For example, *Rhizoctonia*-suppressive strains of *Trichoderma hamatum* and *T. harzianum* are unable to suppress Rhizoctonia damping-off in immature composts, but are extremely effective when introduced into mature composts. Spectroscopic analyses of the organic matter in composts is now being used as a means to predict both compost maturity and the disease suppressiveness of composts. However, this technology is not widely available and is cost prohibitive for routine compost analyses.

Another approach for predicting disease-suppressive properties in composts involves determinations of levels of microbial activity and microbial biomass. In *Pythium*-suppressive composts and peats, direct relationships have been established between both the level of general microbial activity and the amount of microbial biomass and the degree of *Phythium* suppression. While this technique is useful for diseases caused by *Pythium* spp. and perhaps other nutrient-dependent pathogens, its utility in predicting disease suppressiveness for other nutrient-independent pathogens is uncertain. Additionally, because a limited number of composts are disease-suppressive due to non-microbiological mechanisms, this approach is not useful in predicting suppressiveness in these composts.

Despite the requirement of microbial activity for the expression of disease-suppressive properties in most composts used in turfgrass applications, we know little of the specific microorganisms that are involved in imparting disease-suppressive properties. Identification of specific organisms with biological control activity in composts will be a key factor in understanding how composts suppress diseases. This knowledge has proven to be important in developing hardwood bark composts for use in the production of container-grown ornamentals.

Several aspects of the ecology of key compost-inhabiting antagonists in turfgrasses will be important in developing more effective biological control strategies with compost-based organic fertilizers. For example, the ability of antagonists to establish and survive in turfgrass ecosystems is necessary for biological control to occur. The interactions of antagonists with other soil organisms and the soil and plant factors affecting optimum biological control activity will be important in developing strategies with compost-based materials. In addition, these organisms may serve as indicators of how long to compost a material before it can be certified to be disease-suppressive. Research aimed at understanding the fate of antagonistic organisms in soils and on plants following compost applications will aid in the understanding of why composts fail at certain times and in certain locations but not at others. Such research should also help to predict the compatibility of composts and their resident antagonists with other pesticides and cultural practices commonly used in turf management.

As a means of making composts more predictably disease-suppressive, it may be possible to introduce antagonistic organisms with known biological control properties into composting materials at key stages in the curing process. This strategy has been used successfully to produce composts more predictably disease-suppressive and more highly suppressive to a number of plant pathogens.

This approach should enable compost producers to ultimately produce predictably suppressive biological control materials.

Over the past couple of years, a large number of composts have become available for turfgrass applications. Some are properly composted and formulated and of high quality whereas others are not. In the past, quality control was less of a concern when composts were used primarily as fertilizers. However, for the purposes of disease management, quality control is extremely important. Some organic materials that are improperly composted can be extremely phytotoxic. Other improperly composted materials can even accentuate the development of some diseases.

THE USE OF MICROBIAL FUNGICIDES

Microbial fungicides consist of preparations of living microorganisms that are inhibitory to plant pathogens. In the development and use of microbial fungicides, beneficial microorganisms commonly found in nature are isolated from the environment (usually from soils or plant tissues) and their populations are artificially increased. In some instances, they may be culturally or genetically improved in the laboratory, and then they are introduced back into the environment in the form of a fungicide.

Unlike traditional synthetic chemical fungicides, more careful consideration must be made of various aspects of the storage and application of microbial fungicides. Of particular importance is the shelf life of microbial fungicides since the organisms present in such products may not remain viable for extended periods of time. One also needs to consider that, for any microbial-based fungicide to be effective, the organism(s) present in such a product must become established in turfgrass plantings and must remain active throughout the period when disease pressure is greatest. Additionally, the organisms present in these types of products must be compatible with other agrichemicals used in management systems. For example, whereas bacterial preparations should generally be tolerant of most chemical fungicides used in disease management programs, fungal preparations may not and would thus not be as suitable an antagonist as a bacterium.

Through the past couple of decades, it has become apparent that the use of microbial fungicides is fraught with limitations, primarily due to the lack of knowledge about how to adequately produce, formulate and handle living organisms. However, through continued evaluation in agronomic and horticultural systems, it has become evident that microbial fungicides have a very important place in commercial plant production and realistically offer important alternatives to plant health management. They can provide levels of disease control that, in many cases, facilitate reduced applications of fungicides and, in a few cases may eliminate the need for fungicide applications altogether. In addition, microbial fungicides are a potentially important tool in managing fungicide resistance among pathogen populations. Furthermore, the success of sustainable plant production is largely dependent upon the integration of biological and other non-chemical means of control into disease management strategies. Recent developments in Integrated Pest Management (IPM) are a direct result of the awareness of the importance of biological controls in holistic approaches to plant health management.

MICROBIAL FUNGICIDES FOR TURF

Although the biological control of turfgrass diseases is still very much in the developmental stages, the future of microbial fungicides for turf disease control is extremely bright. It is encouraging that a number of chemical pesticide companies are now funding biological control research and have made commitments to the development of microbial fungicides. Strategies by which some companies are developing microbial-based fungicides for turf have been described.

The search for candidate strains of bacterial and fungal antagonists has been promising based on laboratory and greenhouse tests. Antagonists suppressive to take-all patch caused by *Gaeumannomyces graminis* var. *avenae* and to Pythium blight caused by *Pythium aphanidermatum* have been described. We have used Pythium blight as a model with which to develop a rapid and miniaturized assay for the screening of soil bacteria suppressive to various turfgrass diseases. Using this assay, they observed that thatch-inhabiting bacteria from both low and high maintenance turfgrass areas were the most effective Pythium blight antagonists. Among these strains, enteric bacteria were particularly efficacious; strains of *Enterobacter cloacae* were as effective as metalaxyl in suppressing Pythium blight of creeping bentgrass.

Promising results have also been obtained from field studies with biological control agents. Preparations of *T. phacorrhiza* Fr. applied to creeping bentgrass swards effectively suppressed Typhula blight caused by *Typhula incarnata* and *T. ishikariensis*. On creeping bentgrass putting greens, isolates of binucleate *Rhizoctonia* spp. and *Laetisaria arvalis* have been suppressive to brown patch caused by *Rhizoctonia solani* whereas strains of *Enterobacter cloacae* and *Gliocladium virens* have been effective in suppressing dollar spot.

When antagonists are applied at the proper time and in an appropriate manner, they can establish high population levels in bentgrass putting greens and can be as effective as some of the newest chemical fungicides in controlling turfgrass diseases. In our studies, we were able to establish populations of *Enterobacter cloacae* in creeping bentgrass/annual bluegrass turf at levels of 10^8-10^9 cells/g thatch. After 13 wk, populations had declined to only 10^5-10^6 cells/g thatch but these levels were more than adequate to achieve biological control.

The future use of antagonists as microbial fungicides will come only from a better understanding of how antagonists function and how they interact with other turfgrass management inputs. Recent developments in molecular biology have tremendously increased our abilities to answer some of these questions. These advances have been one of the principal reasons that biological control of fungal plant pathogens has become a more viable option for turfgrass disease management than it was just a few years ago.

FUTURE PERSPECTIVES

Biological control of turfgrass diseases is still very much in the developmental stages. Although there are a number of biological control products available for disease control on other commodities, none are available specifically for turfgrass disease control. Despite the past lack of emphasis on biological control research, the last five to ten years have seen tremendous advances in our efforts to understand and develop turf disease biological control. As needs to reduce fungicide dependency and provide sound environmental stewardship become more critical, the more will be the need to develop safe, effective and environmentally sound alternative control strategies.

The potential of composts to suppress turfgrass diseases is clear. At present, applications of these types of materials provide the best alternatives to the use of fungicides on turf and may, in the long term, provide the only means of eradicating pathogens from turfgrass plantings. As we learn more about composting and the benefits of composted materials to plant health, there will undoubtedly be a greater demand from turfgrass managers for high quality disease-suppressive composts. Composted products for use in turfgrass applications are rapidly becoming available. In general, compost procedures are committed to providing the highest quality materials to turfgrass managers at a cost far below that of traditional fungicides. In addition to providing effective disease control, the use of composts will ease the burden on our nation's landfills and foster a commitment to sound environmental stewardship.

Because microbial pesticides are relatively new to the marketplace, it is not yet clear, particularly in the United States, whether they will compete well with chemical fungicides and be acceptable to environmentalists and regulator agencies. Although it is encouraging that more and more biological control products are becoming available, time will tell whether the beneficial properties of biological controls turn out to be effective enough to augment or replace traditional fungicides. It is critical that some of the initial biological control products consistently perform as well as or better than conventional fungicides if microbial fungicides are to rapidly find their way into the marketplace and gain widespread acceptance. Biological control systems such as the *T. phacorrhiza*-Typhula blight system has provided a useful model for the study of turfgrass disease biological control and may likely find its place in the marketplace. Furthermore, as our search for more effective antagonists of turfgrass pathogens expands, suitable bacterial and fungal antagonists will provide a pool from which these organisms can be developed into microbial fungicides.

Biological control is on the verge of a new era of discovery and commercialization. One must believe that the benefits of biological controls, once realized, will overcome any limitations currently impeding development and ultimately change the way in which disease control is approached.