THE MICROBIAL WORLD

The role of this dynamic community in turfgrass management has raised a variety of opinions, questions, and products.

by MATT NELSON

THE SOIL microbial community consists of a wide array of organisms with numerous and many yet-to-be-understood complex interactions (14). Although studies of soil microbiology have been conducted for decades, scientists have recently made considerable progress in furthering our understanding of microorganisms and their function in soils supporting turfgrass growth. Public outcry and opposition to the use of synthetic fertilizers and pesticides have prompted much of the recent research. While very useful findings have been obtained through many painstaking and novel research strategies, these studies have yielded the realization that considerably more research will be necessary to develop solid recommendations for managing soil microbial populations. This article will review soil microbiology and discuss how to select and investigate the use of various products and management techniques. The intent is to provide information for golf course superintendents and other turfgrass managers so they can objectively evaluate the plethora of products that claim to produce better turf by influencing soil microorganisms.

Composting is an excellent means of recycling organic wastes. Studies indicate that composts introduce stable microbial components and provide habitat for indigenous microbial populations, and can improve turfgrass health and suppress certain fungal diseases.

Soil Microbiology

A productive, biologically active soil can contain as many as 45 quadrillion microorganisms in the rootzone of 1,000 square feet of turfgrass (19). This population consists primarily of bacteria, actinomycetes, fungi, and algae. Within each of these groups of organisms are many diverse genera and species whose populations fluctuate widely both spatially and temporally. Among the factors contributing to this variation are energy sources, nutrients, water availability, temperature, pH, atmosphere, and the genetics of the organism (6). The result is a very complex and highly competitive system influenced by a combination of biotic and abiotic forces. The specific function and characteristics of the constituents of the microbial community are not straightforward and are not thoroughly understood.

Fungi are involved in organic matter decomposition, mycorrhizal associations, and turfgrass diseases. Mycorrhizal associations are known to improve nutrient and water uptake, and also stabilize soil aggregates. In fact, mycorrhizal associations have been shown to provide interspecific transfer of phosphorus and other nutrients (3). Endophytic fungi form associations with plants and discourage insect predation. Actinomycetes decompose organic matter, particularly complex organic molecules such as cellulose and chitin. Actinomycetes are also capable of producing antibiotics that may confer disease-suppressive qualities (15, 22).

The bacterial populations in soils contribute a range of benefits to plant growth. Included in these are nutrient cycling, soil aggregation, solubilization of immobile elements, competition with pathogenic organisms, organic matter decomposition, and the production of phytohormones. Bacterial populations and their associative functions are diverse and highly significant to plant productivity. Bacteria tend to utilize simple organic compounds, such as plant exudates, while fungi and actinomycetes are more proficient users of complex organic compounds (6).

Much of the activity described above occurs in the region of the soil environment influenced by roots, known as the rhizosphere. Within this region from the root surface outward approximately 10mm is found enhanced nutrient cycling, exudates that affect pH, redox potential, and nutrient availability; symbiotic associations with soil microbes; colonization by microorganisms; interactions with roots and pathogens; and metal mobility and complexation. More simply put, this region is the dynamic interface between plants and soil where microbial function is in action.

Grasses have a significant amount of rhizosphere due to their fibrous and extensive root systems. Although our understanding of the organisms, processes, and dynamics is increasing, there has been relatively little discovered that would enable turf managers to exploit the rhizosphere for improved turfgrass health. Researchers have, however, used mineral nutrition to affect rhizosphere pH and control root-infecting pathogens (4, 23). Beyond this, there is a host of unsubstantiated product claims that purport to favorably affect rhizosphere processes. In turfgrass systems, there is a significant lack of research to validate these claims, not the least of which include the lack of repeated studies and findings at diverse sites or across a variety of soil systems.

Most soils supporting turfgrass growth contain a very active and diverse microbial population. Some people have alleged that the use of synthetic fertilizers and pesticides reduces or eliminates the microbial community by altering the pH of the soil or causing direct and indirect toxicity to organisms. Except for the presence of inert ingredients in some emulsifiable concentrate formulations that have caused toxicity, preliminary results from one ongoing study indicate that pesticides do not adversely affect most non-target microorganisms (16).

Due to the high productivity and rapid turnover of turfgrass roots, as well as the high lignin content in the stems and leaves, organic matter and microbial habitat are rarely deficient in turfgrass systems (12). The one system that may limit microbial activity due to a lack of favorable habitat is a newly constructed high-sand-content rootzone, likely due to reduced nutrient- and water-holding capacity. Keep in mind, however, that the advent of the sand rootzone system and sand topdressing arose to address severe agronomic difficulties, namely soil compaction and poor drainage of native soil greens. Sand-based rootzones have created physical characteristics that allow golf course superintendents to provide superior playing conditions and also maintain an oxygenated rootzone. Microbial populations generally will stabilize 3-5 years after establishment, so amendments to the sand that can facilitate a more rapid colonization of the rhizosphere should lend stability to the system (6). These amendments would include various organic types, including composts and/or inorganic amendments. The challenge of establishing turfgrass on new, sand-based rootzones could be due in part to the lack of sufficient microbial activity to buffer the system from environmental extremes and harmful pathogens.

Soil Management and Microbial Enhancement

Testing for Soil Microbes

Undisputed is the important role microorganisms play in plant and soil health. The difficulty is in quantifying and qualifying that role. Recent advances in molecular testing capabilities have enabled fairly accurate quantification of the microbial component in soils. While this will not yield a clear understanding of the diverse function and interaction of the various organisms, it is a beginning point for assessing microbial health in soils. Keep in mind that microbial populations fluctuate widely across sites and over the course of a season, however, so testing for microbial activity may produce somewhat confusing results until a large enough database can be assimilated. This currently may not be feasible or cost effective, and it will certainly take time. However, microbial testing may provide comparisons of soil that supports healthy turf versus soil struggling to support turf. Be sure to account for other factors that may be limiting growth, such as sunlight, air circulation, drainage, fertility, traffic flow, etc. (13). Soil testing for microbes may help assess whether microbial activity is influencing turfgrass quality.

Biostimulants

Biostimulant is a loose term that includes microbial inoculum, energy sources for microbes, soil conditioners, plant hormones, and other non-nutritional growth-promoting substances. In recent years, products containing both biostimulants and fertilizers have further muddled this definition. This makes differentiating between fertilizer response and biostimulant response difficult, if not impossible. No doubt this is precisely what the manufacturers of such products have intended, since the non-nutritional component alone may not elicit a plant response.

One group of biostimulants is plant hormones. These products may contain one or more of the following: cytokinins, gibberellins, auxins, abscisic acid, and ethylene. When growing under normal conditions, plants have adequate levels of hormones for normal growth and development. Most physiological processes in plants involve an interaction of several hormones, and individual hormones have several functions. Further, many hormones have different functions in different plant species (8).

Normal hormone production can be influenced by environmental and cultural stress. Different species of plants, growing in different environments, with different stresses, at different times of the year are quite likely to react in different ways. One of these different reactions will undoubtedly be with hormone regulation, and this is consistent with the variability in plant response to hormone applications in research results and field trials across the country. There currently is no evidence to suggest that applications of plant hormones will yield favorable or consistent results with respect to improved plant health. Furthermore, adding hormones to plants beyond normal levels may produce an inhibitory or undesirable effect. Without research information to identify and quantify treatment regimes, it may be wise to avoid tampering with plant hormonal activity (7). Anecdotal evidence and testimonials have been the substitute for independent research results repeated at multiple locations.

Another type of growth stimulant available on the market contains humate or humic acid. These are naturally occurring organic compounds that are the end products of biological decomposition. Accordingly, they are extremely resistant to further decomposition. Products containing humates claim to increase cation exchange capacity, increase microbial activity, and chelate micronutrients. Kussow reviewed manufacturer recommendations for amending a sand-peat rootzone mix with humate and found it to be a very expensive means of increasing the CEC by 13% (9). His review further concluded that iron, copper, manganese, and zinc are rarely deficient in turfgrass soils, thus enhancing micronutrient availability may only provide negligible benefits. Another study clearly demonstrated that since humates are the end result of decomposition and thus resistant to further breakdown, they do not stimulate increased microbial activity (25). Yet another study reviewed the effects of six non-traditional growth-promoting products on the establishment of creeping bentgrass in high-sand-content rootzones. Only one of the products produced significant differences from the control, and the product contained humate. Upon chemical nutrient analysis of the product, however, it was discovered to contain 6% N, 5% P, 2% K, 4% S, and 4% Fe. Using this product at the recommended application rate was equivalent to applying an additional 0.75 pound N, 1.3 pounds of P, and 0.34 pound of K per 1,000 square feet per month (27). It may well be that this response could have been duplicated with conventional fertilizer, and it would seem to request an independent nutrient analysis of any growth-stimulating products you intend to try.

Finally, there have been studies that indicate humates and humic acids can reduce the efficacy of pesticides by reducing their absorption by plants and pathogens (9). It is also reported

Some microorganisms found in certain composts can inhibit turfgrass diseases such as Pythium. *Biological control of turfgrass diseases has proven successful in laboratory studies, but has not been consistently successful in field trials.*

that the fulvic acid component of humates can actually increase the solubility of pesticides and possibly increase mobility (25). Most of the studies that claim any benefit from adding humates were in either nutrient culture or sand culture systems, not in field situations. The variation in humic substances from different sources and lack of research that supports their use on turfgrasses currently do not justify their use in turf management.

Carbohydrate fertilizers, another biostimulant, have not been proven to improve turfgrass stress tolerance or have any lasting impact on soil microbial populations. Again, research on turfgrass and carbohydrate application is lacking, but observations across the country indicate no observable benefits. Any stimulation of microbial activity is likely to be very short-lived.

Microbial Inoculants

Various microbial inoculants have been formulated for use on turfgrass, with claims of accelerated organic matter decomposition, improved nutrient use efficiency and availability, soil conditioning, disease control, mycorrhizal associations, and others. The success of these inoculants has been limited for a number of reasons. At this point, you should be aware that the microbial community is a very diverse and complex set of organisms. The degree of natural competition, antagonism, and predation limits the successful establishment of introduced species. Persistence of applied organisms is further hindered by the continual temporal and spatial fluctuation of microorganism populations (6). Formulation and delivery of the organisms present even more problems for microbial inoculation (15). If the organisms can be kept alive until application, many are sensitive to UV light and must be applied frequently (in some cases nightly) to establish sufficient populations. Although there have been efforts to apply microorganisms through irrigation systems, the results remain largely inconsistent (2). Finally, some companies will not even list what organisms they have formulated, because they are proprietary. Without knowing what is being applied, it is impossible to gauge the potential benefits. These organisms could be detrimental to your turf by actually competing with the beneficial organisms already present in your soil (7)!

Composts

With little doubt, the most promising method of managing and enhancing the activity of soil microbes is with composted organic matter in wastes and other materials. Ironically, this is also one of the oldest agricultural practices. Composts have been shown to add an active microbial component to soils and to stimulate those microbes already present in the soil (14). Well-decomposed organic matter provides excellent habitat and energy sources for soil microbes, and will provide more permanent benefit than inoculation with microorganisms. Composts will effectively enhance soil aggregation, provide nutrients, reduce compaction, and improve soil porosity. Sandy soils amended with compost will exhibit greater nutrient- and water-holding capacity (10). While limited evidence exists, there is some data to suggest amending sand-based rootzones with compost can offer improved establishment and disease control over commonly used peat amendments (5, 14).

The use of composts in turfgrass management presents a viable means of recycling municipal and industrial wastes while improving turfgrass quality. Composts can vary considerably, however, depending on their source. Commonly used composts include brewery sludge, yard wastes, poultry litter, animal manure, municipal wastes, and food wastes. It is recommended to have composts tested for organic matter content, ash content (especially if used as a topdressing), moisture content, pH, nutrients, metals, and soluble salts (10). On-site composting operations should follow guidelines to ensure that the material has been properly and sufficiently composted (14, 20, 28). The disease-suppressive characteristics of composts will be discussed in the next section.

Biological Pest Control

In recent years, considerable focus has been placed on the biological suppression or control of various turfgrass pests, including diseases, insects, and weeds. Reducing the pesticide load on the environment is the primary impetus behind such study. While research has proven effective pest control with various biological entities in the laboratory, few have proven consistently effective in field studies.

Biological control operates on five basic interactions with the turfgrass-soil community: competition, antagonism, predation, parasitism, and pathogenicity (1). The two ways of exploiting these interactions include microbial inoculants and organic amendments. While dozens of organisms with potential as inoculants for disease control have been studied (17, 18, 24), few have demonstrated any efficacy in the field, and only one product (Biotrek 22G, *Trichoderma harzianum*) has been registered for disease control on turf (11, 15). Biological control of insects has been somewhat successful in recent years with such organisms as entomogenous nematodes, soil bacteria and fungi, although registered products are still limited (21, 26).

Serious shortcomings exist in the understanding of the pest control mechanisms themselves, relationships with other organisms in the community, and formulation and delivery technology. Furthermore, foliar disease control with inoculants is limited due to UV sensitivity of the organisms and wide fluctuations of environmental parameters in the turfgrass canopy. The difficulty in delivering organisms to the roots has preempted much success in controlling root diseases. Because successful pest control typically depends on the establishment of high population levels, frequent (and arguably unsustainable) applications become necessary. Injecting organisms through irrigation systems has yet to be proven as an effective method of uniform and consistent microorganism application. Keep in mind that 1) population interactions within the soil are dynamic and interrelated, 2) introduced organisms are slow to colonize habitat and generally fail to persist, and 3) it is unclear whether the introduction of microbes in the environment will produce a lasting change and if the introduction will be beneficial in the long run (1, 15).

Organic soil amendments and additives, particularly compost, have per-

Evaluating Independent Research

- Who (principal investigator) did the research?
- Where was the work done (lab or field, sand or soil)?
- Look for replication, good comparative treatments, and statistically significant differences.
- Have the results been duplicated at another site by another independent researcher?
- Have the results been published in a refereed journal?
- *Slick brochures can be confusing!!!* Don't be fooled by sales techniques.

haps a greater potential for effective biological control of diseases than do inoculants. Well-composted material (2-3 years) often exhibits disease-suppressive characteristics (14). Studies at Cornell University have demonstrated significant and lasting disease suppression of *Pythium* root rot, dollar spot, and snow mold when composts were used as amendments or topdressing (14). Continued research in this area to reveal the microbiological mysteries should help develop more reliable and predictable composts for disease suppression and soil conditioning. As alluded to earlier, proper composting techniques and laboratory testing coupled with on-site testing will reveal what to expect from composts.

New Products

Never before has the turfgrass industry had as many commercially available products for use. Financial responsibility and sound management dictate that product purchasing decisions are of extreme importance. So how does one choose between the good, the bad, and the ugly?

The first place to start is with the product label. There are products that have been registered with the EPA and can legally justify the claims of the product. These are products that contain active ingredients (29). There are unregistered products marketed for various uses, some of which are supported by independent research. Then there are products marketed for various uses without supportive research. These products use testimonials and fancy marketing to make a sale, and often can be classified as snake oils.

Let's be sure we understand the independent, scientific research that supports product use. Be sure you know who conducted the research, where, under what conditions, and the relevancy to turfgrass systems. Also, look for replication in the study, good comparative treatments, and least significant differences. Check closely to see that the results have been duplicated at another site by another independent researcher, and that results have been published in a refereed journal. Make no mistake, slick brochures and displays can be confusing! One product advertisement I recently reviewed claimed the product would cause no grow-in layer, extend the useful life of greens, reduce grow-in time, eliminate the possibility of nitrite (yes, they said *nitrite*, not *nitrate*!) and phosphate leaching, and reduce labor, among other things. This company may need legal counsel as much as scientific counsel. Finally, call the researchers and ask technical representatives what the active ingredients are and what are their modes of action (29). University extension personnel and USGA agronomists can also provide valuable information.

If a product you are interested in passes this initial screening, it is strongly recommended to conduct on-site testing at your golf course. Many of these products are not cheap, and good management involves an economic analysis. Test the material at several locations on the golf course representative of different conditions, replicate (meaning include repeated treatments at each site), and use untreated controls and other treatments in side-by-side comparisons. All too often, new products are tried all over the golf course without a control; thus, it is impossible to determine what effect, if any, the new product has. Perceived benefits could be a result of favorable weather or other management techniques (7, 13). Take consistent, monthly ratings of the plots for color, disease, and rooting depth and mass, and note stress tolerance differences. Good tests require at least two years of field data. Because a product will cause no harm is not reason to use it, and such a decision is representative of poor management.

Conclusion

Turfgrass management is a continually evolving science, and as our understanding of the microbial community in turfgrass systems improves, new products will routinely hit the market. Some of these products will be useful, and many others will not. Independent research will be essential to the development of effective products. Perhaps companies marketing biological products would be wiser to fund some research than to purchase full-page ads in popular trade magazines (if they have faith in their products)!

If completely organic management is ever realized, it will certainly be through a gradual phase-out of synthetic products. Along with the advent of biological products, golf course

On-Site Testing Protocol

- Test products at several locations representing different conditions on the golf course.
- Replicate at each site for best results.
- Use controls (no product) to establish comparisons.
- At least two years of field data are necessary to obtain an accurate assessment.
- Rate the plots monthly to track differences (color, disease, stress tolerance, rooting, etc.).
- Conduct an independent nutrient analysis of new products. You may be seeing a fertilizer response!
- Be honest! Is it the product or favorable weather, better cultivation, an improved growing environment, or other changes in management strategies?

superintendents must also keep themselves apprised of advances in synthetic chemistry. Many new products have been developed from synthesized organic compounds that are effective at very low levels of active ingredients, have low water solubility, short half-lives, and a strong binding potential with soil and organic matter. The new synthetic chemistries are better for the environment than many of the older chemistries.

The importance of a strong microbial community cannot be questioned. The effectiveness of various products available to stimulate microbial activity *can* be questioned. Become familiar with soil microbiology and processes, check for duplicated independent research to support product claims, and test the material yourself to be sure it is effective and makes good economic sense. But whatever you do, don't forget the basic tenets of successful turfgrass agronomy: adequate sunlight, drainage, air circulation, proper fertility, good water management, traffic control, and cultivation.

Soil Microbes

Bacteria	Single-celled organisms without a nucleus. Perform an important role in organic matter decomposition, nutrient cycling, soil aggregation, competition with pathogens, production of phytohormones. Also form symbiotic associations with plants.
Actinomycetes	Filamentous bacteria. Decompose complex organic matter molecules like chitin and cellulose, produce antibiotics, and regulate bacterial populations.
Fungi	Very good degraders of organic matter. Mycorrhizal and endophytic fungi form beneficial associations with plants. Most turfgrass pathogens are fungi.
Algae	Autotrophic organisms. Some fix nitrogen. Excess nutrients can result in an unwanted bloom.
Protozoa	Important in nutrient cycling and organic matter decomposition. Feed on bacteria and control bacterial populations.

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