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

Part one: Fungicide Use and General Properties

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

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

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

Table 1. Breakdown of turfgrass fungicide use by market.

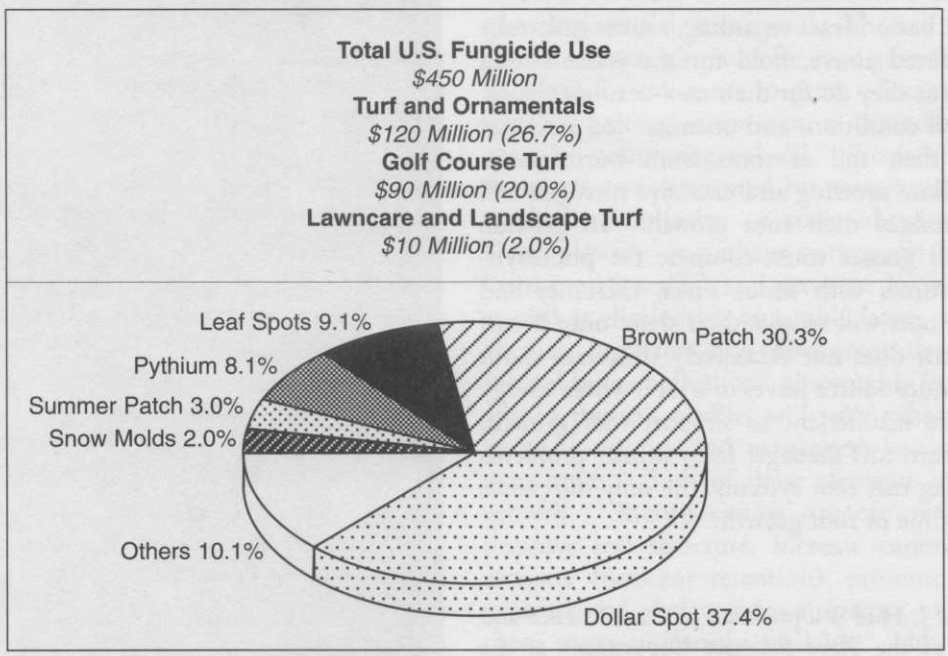

Figure 1. Breakdown of fungicide use on turfgrasses by disease.

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

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

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

Fungicide labels

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

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

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

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

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

Fungicide formulations

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

Table 2. Formulations of turfgrass fungicides.

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

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

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

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

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

Types of turfgrass fungicides

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

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

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

Table 3. Movement of turfgrass fungicides in plants.

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

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

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

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

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

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

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

How fungicides work

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

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

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

Table 4. Mode of action of turfgrass fungicides.

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

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

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

Achieving the maximum levels of disease control from fungicide applications

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

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

cases, the failures could easily be avoided with a little thought and planning.

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

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

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

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

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Terms to Know

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

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

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

Emulsion - suspension of liquid droplets within another immiscible liquid.

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

Fungicidal - treatments that kill fungal pathogens.

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

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

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

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

Penetrant fungicide - those fungicides that enter plant tissues.

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

FOR A COMPLETE INDEX OF TURFGRASS FUNGICIDES AND MANUFACTURERS CONTACT:

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

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

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

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

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