Maximizing Disease Control with Fungicide Applications:

The Basics of Turfgrass Fungicides Part Two: Behavior in Soil

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In the first part of this series I reviewed some of the current trends in fungicide applications. Included in that article was important information on the types of fungicides available to the turfgrass manager and how these fungicides suppress fungal pathogens in plants. In the second part of this series, I review some of the properties of fungicides that affect fungicide behavior in a turfgrass system. This information should be useful in selecting fungicides for application to particular sites and in maintaining environmentally-responsible disease management programs.

The efficacy of fungicides in turfgrass disease control can be related to their behavior in soil. An understanding of the factors that affect fungicide behavior can ultimately lead to more effective fungicide applications. This type of information is among the most important in choosing and predicting the outcome of fungicide applications, yet it is perhaps the least understood of all the aspects of turfgrass fungicide use. Unfortunately, few turfgrass managers have either had access to this type of information or have recognized this kind of information as important to their fungicide programs. Therefore, this article is an attempt to provide turfgrass managers with relevant information on the behavior of fungicides in soil, so that sound fungicide management decisions can be made and predictable fungicide performance can be routinely achieved.

Fungicide efficacy affected by soil properties

Since turfgrass pathogens are generally soil-inhabiting fungi, turfgrass fungicides must find their way to the soil or thatch for effective disease control. The soil-thatch interface under a turfgrass canopy is, without a doubt, one of the most difficult environments in which to apply fungicides successfully. There are many factors that reduce the activity of soil-applied fungicides in this zone; they can be immobilized, degraded, dissipated, and inactivated quite rapidly. This is related to a number of factors, including the degree of sorption of fungicides to organic matter and soil particles, as well as the amount of microbial and chemical degradation, photodecomposition, root absorption, and movement out of the soil profile through volatilization and leaching.

Sorption of fungicides to thatch and soil

Most turfgrass fungicides readily bind to, and are immobilized in, thatch and soil organic matter. While this is desirable in that it minimizes the movement and leaching of fungicides, it can also be detrimental in that it prevents fungicides from achieving their maximum levels of control; in particular, it prevents those fungicides applied for the control of root and crown pathogens from reaching their target. Furthermore, adsorbed fungicides are generally more persistent, thus providing greater opportunities for undesirable side-effects.

Fungicides vary in the degree to which they are adsorbed to soil particles and organic matter; it is mainly a function of the physical and chemical properties of the soil, the chemical properties of the fungicide, and the environmental conditions. The organic matter content is by far the most important determinant of fungicide adsorption. In turfgrasses, the most abundant type of organic matter is in the form of thatch. Since mature stands of some turfgrasses may have a considerable thatch layer, this can present real problems in maintaining effective fungicide treatments.

All things being equal, as the thatch layer or soil organic matter content increases, so too will the degree of fungicide adsorption. Those fungicides most likely to be immobilized in thatch include contact fungicides such as anilazene, chlorothalonil, mancozeb, chloroneb, quintozene, and etridiazole, and the penetrant fungicides propamocarb and vinclozolin (Table 1).

Table 1. Water solubility and thatch adsorption potential of turfgrass fungicides.

Fungicide	Water Solubility (ppm)	Potential for Thatch Adsorption[a]
Quintozene	0.1	High
Chlorothalonil	0.9	High
Thiophanate methyl	3	Low
Vinclozolin	3.4	High
Benomyl	4	Moderate
Mancozeb	6	High
Anilazene	8	High
Chloroneb	8	High
Flutolanil	9.6	Unknown
Iprodione	13	Moderate
Fenarimol	13.7	Moderate
Thiram	18	Moderate
Triadimefon	64	Low
Etridiazole	117	Moderate
Propiconazole	100	Moderate
Cyproconazole	140	Moderate
Metalaxyl	8400	Low
Fosetyl Al	120,000	Low
Propamocarb	1,005,000	High

[a] Low adsorption = K_{oc} values $\leq$ 300; Moderate adsorption = K_{oc} values between 300 and 1000; High adsorption: = K_{oc} values >1000.

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Soil properties important in fungicide adsorption

Soil type can also affect the immobilization of turfgrass fungicides. As the clay content and the cation exchange capacity (CEC) increase, so too does the degree of fungicide adsorption. On golf course turf, however, high sand content growing mixes and highly-modified soils limit the clay content in the root zone, making this a relatively unimportant consideration in fungicide performance on these types of soils. However, organic amendments, as well as some types of inorganic amendments, that increase CEC (e.g., zeolites) may have significant effects on fungicide efficacy.

Soil temperature may also affect fungicide adsorption. In general, as soil temperatures increase, adsorption decreases; however, for those fungicides that have a greater potential for thatch adsorption, the effects of soil temperatures are much more pronounced.

Particularly for fungicides that are more soluble in water, wide changes in soil pH will drastically alter the degree of fungicide adsorption. For example, considerably more adsorption would be expected in alkaline (pH >7.0) soils than in acidic (pH ≤ 5.5) soils; this is not particularly important if the soil pH from site to site is relatively uniform. Soil water content will also affect fungicide adsorption insomuch as adsorption increases dramatically in very dry soils.

Fungicide properties affect adsorption

The chemical properties of the fungicides being applied are important predictors of soil or thatch adsorption. Polar or permanently charged fungicide molecules are more likely to be adsorbed than non-polar or neutral molecules. In general, polar fungicides remain more polar in alkaline, rather than in acidic, environments. With the exception of fosetyl Al, which is the most polar of them all, the majority of the turfgrass fungicides used today are quite non-polar.

Of equal importance is the water solubility of the fungicide (Table 1). As the water solubility increases, the amount of adsorption generally decreases. For the most part, many of the contact fungicides are not readily soluble in water and may be tightly adsorbed to thatch. Those fungicides that are least likely to adsorb, because of their higher water solubilities, are metalaxyl, and triadimefon. Propamocarb and fosetyl Al are unusual fungicides in that they are not only extremely water soluble, but are also highly adsorbed to organic matter; whereas, as a result of its other fungicide properties, thiophanate methyl has both low solubility and low potential for thatch adsorption.

Microbial degradation of fungicides

All turfgrass fungicides are subject to varying degrees of microbial, plant, and chemical degradation in soil. These are the only processes whereby the fungicide can actually disappear from the environment; thereby reducing the total environmental load of the fungicide. Since many soil microbes get their energy from the breakdown of carbon-containing compounds, all turfgrass fungicides have the potential to serve as a food source for microorganisms in turfgrass soils. Even if the fungicide does not directly serve as a food source, decomposition may still occur; the metabolic enzymes produced by soil microbes, during the degradation of other forms of organic material, often contribute to the decomposition of fungicides. Frequently, the active ingredient molecule is broken down into other molecules with no fungicidal or detrimental side effects. However, in a couple of cases (e.g., benomyl and triadimefon), the fungicide active ingredient is broken down into yet other fungicidal compounds that have their own behavior and efficacy in turfgrass soils.

Generally, the greater the soil microbial populations and the greater the microbial activity, the more likely a fungicide will degrade. However, studies have shown that microbial degradation of fungicides does not occur immediately after the application of the material. Rather, there is a lag period during which microbial populations shift, favoring those microbes possessing the appropriate enzyme systems to degrade the introduced fungicide. After these microbial populations acclimate to the introduced fungicide, degradation can proceed at a higher rate. Over time, the continued application of the same fungicide to the same site will very quickly result in reduced fungicide efficacy, if not from enhanced microbial degradation, then from the development of fungicide resistance. Fungicide resistance will be covered in more detail in a future chapter of this ongoing series on fungicides.

Soil properties affect microbial degradation

The rate at which turfgrass fungicides are degraded by soil microbes depends, to a large extent, on fungicide chemical properties and fungicide concentration; it also depends on a number of soil factors including moisture, pH, oxygen content, nutrient status, clay content, organic matter content, and, perhaps most importantly, the type of soil microbial community. The variety of soil microorganisms that degrade turfgrass fungicides have very specific metabolic capabilities. The population levels of these specific microbes directly affect the level of fungicide degradation. As these microbes degrade the active fungicide molecules, the degradation products further stimulate other microorganisms capable of degrading the fungicide metabolites.

Those fungicides more resistant to microbial degradation are those that are less available in the soil solution. For example, those fungicides that more readily bind to thatch, that are not very water soluble, and are known to persist in soil for appreciable periods of time, will be less prone to microbial degradation. This persistence in soil is usually expressed as the half-life of the fungicide, which is the time it takes for half of the original applied fungicide to degrade (Table 2). Fungicides such as anilazene, thiram, and vinclozolin are rapidly degraded in soils, whereas propiconazole, cyproconazole, and benomyl are quite persistent.

Volatilization of fungicides

Volatilization refers to the evaporation of fungicides from the spray, the turfgrass foliage, and the soil surface into the atmosphere. Volatile losses of fungicides are significant from two different perspectives: first, volatile losses remove the fungicide from the target site, thus reducing the effectiveness of the fungicide; second, volatile losses increase the inhalation hazard to applicators and others who come into contact with treated turf. Efforts, therefore, should always be made to minimize these losses where possible.

The degree of volatilization of a given turfgrass fungicide is related not only to the inherent vapor pressure of the fungicide at a given temperature (Table 3), but also to environmental factors and chemical processes at the soil-air-water interface. For example, volatilization may be affected by the soil water content and bulk density. Generally, as soil water content increases, volatilization decreases; however, in very dry soil, volatilization is also reduced as increased adsorptive processes limit the amount of fungicide free in the soil solution. Increases in bulk density tend to reduce the diffusion of the fungicide to the soil surface and further increase fungicide adsorption.

Precipitation and irrigation will also reduce the amount of volatilization by transporting fungicides away from the turfgrass foliage and soil surface, where the greatest amount of volatilization occurs, and by increasing the soil water content. The frequency of rainfall or irrigation can also indirectly affect volatilization by affecting the degree of water evaporation. Water evaporation will transport most fungicides to the soil surface where volatilization can occur; therefore, the greater the frequency of irrigation or rainfall, the lower the potential for volatilization losses.

Wind speed also indirectly increases volatile losses of fungicides by increasing water evaporation rates. Generally, wind serves to mix the stagnant layer of air adjacent to the turfgrass foliage, thereby increasing the overall evaporation rates and the volatilization potential of turfgrass fungicides. Those fungicides that adsorb more tightly to thatch and soil will be unaffected by evaporative processes, but those that are normally free in the soil solution will have considerable increases in volatilization losses.

Table 2. Half-life and persistence of turfgrass fungicides in soil[a].

Fungicide	Half-Life in Soil	Persistence Classification
Fosetyl Al	20 Min. – 1.5 Hr	Very short
Anilazene	0.5 – Days	Very short
Thiram	0.5 – 15 Days	Short
Vinclozolin	1 – 31 Days	Moderately short
Chlorothalonil	5 – 90 Days	Moderately short
Mancozeb	6 – 139 Days	Moderately persistent
Triadimefon	6 – 28 Days	Short
Iprodione	7 – 160 Days	Moderately short
Propamocarb	10 – 27 Days	Short
Chloroneb	10 – 180 Days	Moderately Short
Thiophanate methyl	10 – 28 Days	Short
Etridiazole	20 Days	Short
Fenarimol	20 – 365 Days	Highly persistent
Quintozene	21 – 434 Days	Highly persistent
Flutolanil	40 – 60 Days	Moderately short
Propiconazole	40 – 123 Days	Highly persistent
Metalaxyl	70 – 160 Days	Moderately short
Cyproconazole	80 – 100 Days	Moderately persistent
Benomyl	90 – 360 Days	Highly persistent

[a] Fungicides ranked from the shortest half-life to the longest.

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Table 3. Vapor pressures of turfgrass fungicides and their potential for volatilization.

Fungicide	Vapor Pressure[a] (mPa), 20-25°C	Potential for Volatile Losses
Chloroneb	400.0	High
Etridiazole	19.0	High
Quintozene	12.7	High
Thiram	2.3	Moderately High
Flutolanil	1.77	Moderately High
Propamocarb	0.800	Moderate
Metalaxyl	0.75	Moderate
Chlorothalonil	0.076	Low
Fenarimol	0.065	Low
Triadimefon	0.06	Low
Vinclozolin	0.016	Low
Fosetyl Al	0.013	Low
Thiophanate methyl	0.0095	Very Low
Propiconazole	0.0056	Very Low
Benomyl	0.0049	Very Low
Cyproconazole	0.00346	Very Low
Anilazene	0.0000008	Very Low
Iprodione	0.0000005	Very Low
Mancozeb	negligible @ 20°C	Very Low

[a] Fungicides ranked from most volatile to least volatile.

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As mentioned earlier, volatilization losses have important implications on human health. In this regard, there are a number of important factors to consider. First, it is important to note that the greatest volatilization losses occur during, and within a few hours after, application. Furthermore, volatilization losses are greater at warmer temperatures, particularly during the middle to latter part of the day. Therefore, if the fungicide being applied is particularly prone to volatilization losses, precautions should be taken to adjust application schedules to avoid the warmer times of day and to wear the proper protective clothing to avoid inhalation dangers during, and the hours immediately following, applications. Second, the concentration of the applied fungicide affects the degree of volatilization: the greater the fungicide concentration, the greater its vapor concentration. Therefore, reducing application rates, or increasing the amount of water in which the fungicide is applied, will help to minimize volatile losses of fungicides and reduce the risk of unnecessary exposures.

It is also important to recognize that the formulation of the fungicide will affect its degree of volatilization. Wettable powder and granular formulations generally have a greater volatilization potential, following application, due to either a thin film remaining on the turfgrass foliage, or the granular particles remaining on the soil surface. Some studies have linked volatile losses with the degree of dislodged fungicide residues; therefore, the greater the degree of soil incorporation of the fungicide, the lower will be the volatilization of the fungicide.

Fungicide leaching

Fungicide leaching occurs whenever the applied fungicide is not taken up by the plant, degraded by soil microbes, broken down by chemical reactions in soil, decomposed by light, adsorbed to thatch and clay particles, or volatilized. The leaching of pesticides in turfgrass systems has been discussed in considerable detail in a previous issue of *TurfGrass TRENDS* (September 1995) and will not be discussed at any length here.

Keep in mind that all of the factors discussed in this article will affect fungicide leaching. Turfgrass fungicides, as a group, however, are not particularly susceptible to significant amounts of leaching when applied to mature stands of turf grown on soils with some level of organic matter or clay. Leaching usually becomes a problem when fungicides are applied to immature stands of turf on high sand content soils and when applications at high rates are followed by considerable amounts of rainfall or irrigation. Of all the turfgrass fungicides, fenarimol, metalaxyl, propiconazole, and triadimefon have the highest potential for leaching; however, these fungicides pose little or no reason for concern under normal climatic conditions and operating procedures. Furthermore, by making simple adjustments in cultural management and application techniques, any potential leaching problem can be easily avoided.

Management recommendations

The importance of understanding the behavior of fungicides in soil should now be quite apparent. These properties should be used as a guide in making decisions about the application of specific fungicides to specific sites for specific disease problems. It is important to recognize that while the fungicides applied to turfgrasses do not normally move about or disappear from a turfgrass system to any significant degree, their presence alone does not insure efficacy since they are rapidly transformed or inactivated. For these reasons and others pointed out in Part I of this series, fungicides fail from time to time.

Much of the behavior of the fungicide being applied can be predicted from a limited amount of knowledge of the soil properties and the environmental conditions at the site. For example, if faced with the decision of what fungicide to apply to a golf green with brown patch symptoms, you could choose from a vast number of products and formulations all labeled for brown patch control. If the green to which you were applying the fungicide was a native soil green with a high clay and organic matter content, you may want to choose a fungicide such as cyproconazole or propiconazole. Both have higher water solubilities, and lower potential for adsorption to clay and organic matter, than do many other brown patch fungicides. On the other hand, if the green was a high sand content green in an exposed sunny area, you may want to choose a fungicide such as iprodione that has a relatively short half life in soil and is relatively non-persistent. This would avoid any potential leaching losses. Furthermore, on this type of a green, soil temperatures and evaporation rates would be expected to reach relatively high levels, increasing the chances of volatilization losses. Since iprodione has a very low volatilization potential, a short persistence, and only moderate potential for adsorption, this would be an ideal choice for that site.

Aside from choosing a fungicide based on its inherent properties and the soil conditions, making small adjustments in application rates, timing, formulation, and post application irrigation schedules will help to maintain the maximum amount of fungicidal activity with the least amount of undesirable side effects. Furthermore, thatch management is critical to maintaining minimal immobilization and maximum efficacy.

In the coming months, I will continue the discussion of turfgrass fungicides, covering some of the plant and pathogen factors that affect fungicide efficacy, handling, applying and monitoring fungicides, record keeping, human and environmental health considerations, and how to interpret fungicide test results. Stay tuned!

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Terms to Know

Acclimate - To adapt to a new chemical, physical, or biological environment.

Adsorption - The retention of solids, liquids, or gasses at an interface.

Bulk density - The weight of soil per unit volume.

Cation exchange capacity (CEC) - The sum total of all exchangeable positively charged ions, such as sodium, magnesium and potassium, that a soil can adsorb. Expressed as milliequivalents per gram of soil.

Half-life - The time required for half of the original amount of applied fungicide to disappear.

Immobilization - The reduction in movement of fungicides.

Leaching - The removal of fungicides dissolved in water from upper soil layers to the ground water.

Metabolites - Products of microbial metabolism.

Microbial community - Interacting populations of microorganisms.

Non-polar molecules - Molecules with no electrical charge.

Polar molecules - Molecules possessing two equal and opposite electrical charges.

Vapor pressure - The pressure exerted by a fungicide in its gaseous state in equilibrium with that in the liquid state. A measure of the potential of a fungicide to convert to a gas.

Volatilization - The conversion of a fungicide from a liquid to a gaseous state and its subsequent escape from the soil.

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Poa annua Management

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Poa annua, or annual bluegrass, is regarded as either a help, a hindrance, or purely a frustration, depending on your particular situation. This grass is often described as a light green to yellow green annual plant with boat-shaped leaf tips. It usually germinates in the fall and flowers profusely, even at mowing heights as low as those found on golf greens. Unlike Kentucky bluegrass, annual bluegrass tolerates shade; however, survival can be poor during hot, dry summers, such as those some of us experienced in 1993 and 1995.