Volume 8, Number 6

TURFAX™

November–December 2000

of the International Sports Turf Institute, Inc.

The International Newsletter about Current Developments in Turfgrass

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Fungicides: Plant Uptake and Mode of Action

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Fungicides are somewhat mysterious chemicals because their behavior on or inside of plants, and how they physiologically affect microorganisms, is not clear. **Fungicides are divided into three types: contacts, penetrants, and systemics.** Fungicides also are classified by mode of action or chemical composition. These classification systems or groupings, and some other terms associated with fungicides, are confusing and sometimes misleading. For example, most fungicides are not fungicidal, and penetrants can provide activity on the surface of tissues as well as from within tissues. Most fungicides are actually fungistatic. That is, most fungicides only prevent growth or development of fungi and do not actually kill them in soil. Several contact fungicides can kill fungal spores as they germinate, but even most contacts tend to be fungistatic. Another contradiction centers on the use of the word systemic. A systemic chemical by definition is capable of moving throughout a plant from leaves to stems to roots or vice versa. In fact, **the only truly systemic turf fungicide is fosetyl aluminum (Aliette Signature®). Most other so-called systemics are better referred to as penetrants, because they either remain localized inside tissue or primarily move upward in the xylem** in response to the transpiration stream. The translocation behavior and mode of action of penetrants are described below and are summarized in the table on page 3.

The largest number of fungicides in the turf market having the same mode of action are the **sterol inhibitors (SI).** They also may be referred to as DMI or demethylation inhibitors. Most of the SI fungicides are chemically classified as triazoles. When applied to a turfgrass plant, **an SI fungicide will penetrate tissue and move upward (i.e., acropetal penetrant) from the point of tissue contact. The SI's also are capable of lateral diffusion from the upper to lower surface and vice versa,** and may exhibit limited downward movement. Downward or basipetal movement of SI's, however, is only a few millimeters. Hence, **the molecules of an SI fungicide that contact leaf tissues are highly unlikely to translocate to roots.** However, chemical that contacts basal leaf sheaths, or runs down between leaf sheaths, may be transported into axillary buds and possibly stems.

Azoxystrobin (Heritage®) is chemically classified as a strobilurin fungicide. Strobilurin was derived from a mushroom fungus and stabilized to prevent rapid deterioration in the environment. **Azoxystrobin is a penetrant that moves across leaves from upper to lower leaf surfaces and vice versa, and also moves upward**

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in the xylem from the point of contact. Hence, Heritage® is an *acropetal penetrant.* Azoxystrobin provides disease control by interfering with respiration and resulting production of a key energy compound (i.e., ATP) in sensitive fungi.

The **other acropetal penetrants listed in the table on page 3 represent diverse chemistries and modes of action. Among flutolanil (ProStar®), propanocarb (Banol®), and mefenoxam (Subdue MAXX®),** it is likely that only mefenoxam is single site specific. The mefenoxam molecule is an isomer or mirror image of the metalaxyl (Subdue®) molecule. Mefenoxam has about twice the activity of metalaxyl and therefore is used at half the rate of metalaxyl. Regardless, both have the same mode of action and metalaxyl is no longer available.

There is a third fungicide group known as **site absorption or *localized penetrants.* These fungicides are absorbed into tissues, but they do not move significantly beyond the site of uptake. Chloroneb (Terremec SP®), iprodione (Chipco 26GT®), and vinclozolin (Curalan®, Touche®, Vorlan®)** are localized penetrants. Iprodione and vinclozolin are chemically related (i.e., dicarboximides) and they have the same mode of action. **The mode of action of all of the aforementioned localized penetrants is non-site specific, that is, they interfere with two or more biochemical processes in susceptible fungi.** The exact number of processes disrupted and the precise nature of the biochemical processes altered is unclear for this group.

Trifloxystrobin (Compass®) is similar to a localized penetrant, but its behavior in plants is unique. **Trifloxystrobin penetrates leaves and moves from upper to lower leaf surfaces and vice versa, but most molecules become fixed within the waxy portion of the cuticle.** Compass® does not move upward in the xylem. An equilibrium exists between trifloxystrobin molecules inside the leaf and those embedded in the cuticle. **As molecules in the leaf are metabolized or otherwise broken down, additional molecules will move into the leaf from the wax to maintain the equilibrium. Because of this unique equilibrium, trifloxystrobin is described as being *mesostemic.* This dynamic accounts for the generally long residual effectiveness of trifloxystrobin,** when compared to other localized penetrants. The mode of action of trifloxystrobin is the same as azoxystrobin. That is, stobilurins disrupt respiration and deplete the production of energy compounds (ATP) needed by living cells to function.

Contact fungicides* provide activity outside of plants and protect only those tissues they contact.** Because contact fungicides are subjected to removal from tissues by mowing and the forces of the environment (i.e., wash-off, UV light degradation, microbial breakdown, etc.) **they tend to provide a relatively short period of protection.** The number of contact fungicides available for use on turfgrasses is dwindling and currently include: chlorothalonil (Daconil Ultrex®, others), ethazol (Koban®), maneb (Pentathalon®), mancozeb (Dithane®, Fore®, Protect®), thiram (Spotrete®, Defiant®), and fluidoxonil (Medallion®). Medallion is currently marketed for use on ornamentals, but the label may be expanded to include turf diseases. **Contact fungicides, however, are extremely important in disease management programs because they generally are free of resistance problems.** Contacts also tend to have more rapid curative (i.e., knockdown) activity than penetrants and therefore are preferred in a tank mix combination with a penetrant once disease systems have appeared. Contact fungicides and most localized penetrants normally interfere with several, mostly unknown biochemical or physiological processes in susceptible fungi. In more technical terms, **the mode of action of contact fungicides and most localized penetrants is *non-site specific, meaning that several genetic barriers exist in order for resistant biotypes to develop. Conversely, **SI's, strobilurins, and benzimidazoles (i.e., Cleary's 3336® and Fungo 50) are *single-site specific.*** That is, they only disrupt one specific biochemical or physiological process in a susceptible fungus. **The single process disrupted is often controlled by a single gene and therefore the probability of a resistant biotype developing is greatly increased.** For example, SI fungicides interrupt the production of ergosterol in sensitive fungi by blocking a single demethylation reaction. Ergosterol is a sterol (a type of lipid) used in minute quantities by fungi to produce membranes. In the absence of this sterol, membrane form and function are impaired and the fungus cannot grow. Benzimidazoles prevent spindle fiber development during mitosis so cell division does not occur and strobilurins interrupt electron flow during respiration at one site in mitochondria. Because these fungicides interrupt only one of thousands of biochemical reactions occurring in fungi the probability of the existence of a small subpopulation of tolerant

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biotypes in the ecosystem is likely. **Continuous use of fungicides with the same mode of action can selectively remove susceptible biotypes, which allows the resistant biotypes to proliferate and eventually dominate in a turf.** Indeed, **nearly all documented resistance problems are associated with penetrants and extremely few have been related to the use of contact fungicides.** In the next issue of TURFAX, fungicide resistance and other nontarget effects of fungicides will be described.

The translocation behavior or movement of fungicides that penetrate plant tissues and their mode(s) of action.

Common Name	Trade Name(s)	Mode(s) of Action
	PENETRANT	
	Upward/Acropetal Movement	
Azoxystrobin	Heritage	Inhibits respiration
Flutolanil	ProStar	Inhibits a respiratory enzyme*
Mefenoxam	Subdue MAXX	Blocks RNA synthesis*
Propamocarb	Banol	Inhibits membrane function*
Thiophanate	CL 3336, Fungo	Inhibits mitosis
	Upward and Limited Downward/Basipetal Movement	
Cyproconazole	Sentinel	Sterol inhibitor/DMI
Fenarimol	Rubigan	Sterol inhibitor/DMI
Myclobutanil	Eagle	Sterol inhibitor/DMI
Propiconazole	Banner MAXX	Sterol inhibitor/DMI
Terbuconazole	Lynx	Sterol inhibitor/DMI
Triadimefon	Bayleton	Sterol inhibitor/DMI
Triticanazole	Triton	Sterol inhibitor/DMI
	True Systemic/Upward and Downward Movement	
Fosetyl aluminum**	Aliette Signature	Triggers plant resistance mechanisms, blocks mycelial development, inhibits spore germination
	SITE ABSORPTION**	
	(Taken-up In Tissue But No Significant Movement)	
Chloroneb	Terremec SP, Terraneb SP	Interferes with enzymes*
Iprodione	Chipco 26GT, Rovral	Membrane damage, inhibits cell division*
Vinclozolin	Curalan, Touche, Vorlan	Membrane damage, inhibits cell division
Trifloxystrobin	Compass	Inhibits respiration

* The precise mode of action of most fungicides other than the benzimidazoles, strobilurins, and sterol inhibitors is imperfectly understood.

** Site absorption fungicides and fosetyl aluminum provide non-site specific modes of action.