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IN THIS ISSUE

Fungicides: Plant Uptake and Mode of Action

Peter H. Dernoeden

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.

FEATURE ARTICLE

Understanding Low-Temperature Kill

James B Beard

The kill of grass plants caused by ice crystal formation at temperatures below 32°F (0°C) is termed low-temperature kill. It may be of either an intercellular or extracellular nature, in which the brittle protoplasm organization is fatally damaged via a mechanical destruction. The absolute temperature at which a particular species and cultivar is killed may vary substantially depending on the (a) hardiness level the plant achieved, (b) rate of freezing, (c) rate of thawing, (d) number of times frozen, (e) length of time frozen, and (f) post-thawing treatment which is either favorable or unfavorable for growth.

Certain cultural practices can be utilized to minimize the extent of direct low-temperature kill, such as: (a) ensure drainage of excess water by adequate surface drainage through the proper contouring and use of open catch basins, plus as appropriate and affordable, the use of a well-drained high-sand root zone combined with subsurface drainlines to ensure rapid removal of excess water, (b) maintain a relatively low nitrogen nutritional level during the autumn hardening period such that it sustains only minimal growth, (c) maintain a balance of essential plant nutrients, plus a high potassium level, (d) raise the cutting height to maximize carbohydrate production and provide increased canopy insulation, (e) judicious irrigation during the autumn hardening period, which avoids waterlogging and excessive shoot growth, and (f) selection of low-temperature kill hardy turfgrass species and cultivar(s).

Low-temperature kill hardiness is the ability of the grass plant to survive potentially lethal low temperature stress at temperatures below 32°F (0°C). Plant hardiness is achieved primarily by the redistribution water, and includes lowering the hydration level of the critical meristematic tissues. This hardening process typically occurs at temperatures in the range of 35 to 40°F (2–5°C). Any cultural practice that stimulates leaf growth will adversely affect the hardiness process. The relative low-temperature kill hardiness of 31 autumn-hardened turfgrasses is shown in the accompanying table.

Relative Low-Temperature Kill Hardiness	Turfgrass
excellent	rough bluegrass
	creeping bentgrass
	turf timothy
good	Kentucky bluegrass
	Canada bluegrass
	velvet bentgrass
	crested wheatgrass
	colonial bentgrass
	redtop
moderate	creeping bluegrass
	fine-leaf fescues
	American buffalograss
	blue grama
	annual bluegrass
	perennial ryegrass
	tall fescue
	meadow fescue
	Japanese zoysiagrass
poor	dactylon bermudagrass
	manila zoysiagrass
	seashore paspalum
	hybrid bermudagrass
very-poor	centipedegrass
	mascarene zoysiagrass
	common carpetgrass
	annual ryegrass
	bahiagrass
	St. Augustinegrass
	kikuyugrass
	tropical carpetgrass
	serangoongrass

FEATURE ARTICLE

Roundup is More Rainfast than Previously Thought

Fred Yelverton

Glyphosate products, sold by the brand name of Roundup®, are the most commonly used pesticides in the world by a sizeable margin. One of these products, **Roundup Pro®, is commonly used by turfgrass managers to deal with a variety of management issues, including standard weed control and, perhaps most importantly, turfgrass renovation.** Glyphosate-containing products are still the most effective products used to kill bermudagrass. Essentially all turfgrass renovation programs include the use of glyphosate products.

Glyphosate was first synthesized in the mid-1960s by Monsanto. Glyphosate was first sold as Roundup® in the mid-1970s for noncropland weed control in the United States, the United Kingdom, and Malaysia. By 1997, Roundup Ready® (crop plants genetically modified to withstand Roundup® applications) were being commercially planted and currently represent 60% of the U.S. soybean crop. This same technology has been developed in turfgrass species, but these genetically altered turf species have not yet been released.

Turfgrass managers know Roundup® to be very effective for controlling a wide range of weeds. **The major advantage of Roundup® is its effectiveness for control of perennial weeds.** This is accomplished because the herbicide is translocated to meristematic tissues and underground structures such as roots, rhizomes, tubers, etc. The product kills plants by interfering with essential amino acid synthesis.

But what are the disadvantages of Roundup®? Most turfgrass managers would quickly mention two issues: (1) Roundup® is slow to kill plants, and (2) the herbicide must have a long rain-free or irrigation-free period after application. To state it another way, Roundup® is perceived to be not very rainfast. The old Roundup® product, and many currently labeled generic glyphosate products, state on the label "rainfall or irrigation occurring within 6 hours may reduce effectiveness." The newest Roundup® products in turf (Roundup Pro® and Roundup ProDry®) state on the label "heavy rainfall soon after application may wash this product off foliage and a repeat application may be required."

Are these statements necessary? And precisely how long does this product need to be on the plant foliage before rainfall or irrigation will reduce effectiveness? Over the last 18 months, this issue has been investigated at the Turfgrass Field Laboratory at North Carolina State University. Tall fescue was sprayed with Roundup®, Roundup Pro®, Roundup ProDry®, and an experimental Roundup® formulation; and 0.25 inch (6.4 mm) of irrigation was applied either 15, 30, or 60 minutes after herbicide application.

As noted in the table below, 0.25 inch of irrigation applied as soon as 15 minutes after Roundup® application still resulted in more than 90% tall fescue control with 3 of the 4 Roundup® treatments. Only the old Roundup® formulation failed to provide more than 90% control. When irrigation was applied 30 minutes after application, all Roundup® formulations provided at least 95% control of tall fescue. **These data suggest that Roundup® is more rainfast than the precautions on the label would suggest.**

Effects of 0.25 inch of irrigation on tall fescue control 36 days after treatment with four Roundup® formulations.

	Irrigation Timing (0.25 inch) following Roundup® Application			
Roundup® Formulation	**no rainfall**	**15 minutes**	**30 minutes**	**60 minutes**
	% Tall Fescue Control			
Roundup®	100	89	95	93
Roundup Pro®	100	94	96	99
Roundup ProDry®	100	92	96	94
Experimental Roundup®	100	96	99	98

FEATURE ARTICLE

Causes of a Dark-Green Color in Turfgrasses

James B Beard

Many individual turfgrass users prefer a dark-green color, although this does not necessarily indicate a healthier turf. Some grasses inherently have a genetically controlled light-green color and still are a healthy, competitive species and/or cultivar. There are numerous causes of a dark-green color, some of which are beneficial and others potentially of negative concern. They include the following:

Nutritional Benefits. Nutrients such as nitrogen (N), sulfur (S), and magnesium (Mg) are constituents of the chlorophyll molecule, and thus are required in minimal threshold levels to achieve the desired green color. Iron (Fe) also is an essential nutrient, but is not a constituent of chlorophyll. Rather iron is required for synthesis of the chlorophyll molecule. **Iron and/or nitrogen can impart a significant darker green color, whereas all four elements improve color if applied when at a deficit tissue level.** One advantage of iron is that it can enhance the dark-green color without excessive shoot growth, which occurs with nitrogen when used at high levels.

Environmental Stress Negative Effect. During chronic environmental stresses such as heat, drought/water and cold, there is a distinct darkening of the turf associated with a very slow to minimal shoot growth stage. **In this situation the darkening of color caused by environmental stress may be a sign precluding significant injury and possible death of the turfgrass.**

Growth Regulator Response. Most growth regulators used for slowing the vertical shoot growth of turfgrasses also impart a darker green color. One possible contributing mechanism to this response is the reduced amount of shoot growth occurring, which allows increased nutrient availability for the existing grass shoots. **Associated with this will be an increased carbohydrate reserve accumulation, which can cause a darker green color,** as well as improve the recuperative potential from turf injury.

Pesticide Negative Effect. A number of pesticides used on turfs are reported to impart a darker green color for a period of time following application. The mechanism involved in this case may be an adverse physiological effect via atypical chemical reactions in the plant. **In this case the dark-green color could be a sign of a less healthy plant and an overall weakened turf.** Thus, in this situation a darker green turf is not a beneficial response.

Nutrient Harvesting from Golf Course Ponds?

James B Beard

While visiting turfgrass facilities in the Queensland area of Australia for the purpose of advising on the establishment of a new government turfgrass research program I found an interesting set of observations. The Queensland government agency charged with environmental protection had been promoting the planting of certain aquatic plants for the purpose of harvesting unwanted nutrients from ponds and lakes. Specifically targeted have been golf courses, under the assumption that a significant nutrient load enters these water bodies due to the golf course maintenance practices.

Several years ago two golf courses initiated programs to plant these recommended aquatic plants with the objective of removing nutrients from the water. During discussion with the superintendents in charge, it was indicated that **great difficulty was encountered in getting these aquatic plants established.** It was **only after fertilizer was applied to the water sites that the aquatic plants were successfully established, and they were only sustained on a longer-term basis if periodic fertilizations were made to the multiple pond areas occupied by the aquatic plants.** In other words, a minimal and insufficient amount of fertilizer nutrients was being carried in the runoff water into these ponds to sustain even minimal growth of the aquatic plants. This indicates that **under the conditions on these golf courses, the turfgrass nutrient fertilization programs were not a negative concern to the quality of these water bodies.**

JB Comments

Turfgrass-Soil Diagnosis Procedure

James B Beard

It continues to amaze me as to how many individuals, both consultants and turfgrass professionals, involved in the diagnosis of turfgrass problems fail to look below ground. **In a majority of the cases, I can draw more conclusions concerning past and potential future turfgrass problems by examining the below-ground portion than can be accomplished by aboveground observations of the turf.** My preferred procedure for this diagnosis includes the following:

(1) **Use a 4-inch (10 cm) diameter cup cutter,** rather than the 3/4 inch (1.9 cm) diameter soil sample probes or the flat profile samplers that are available.

(2) Immediately after the 4-inch diameter core is removed from the cup cutter, assess the smell by traversing the length of the profile using **a close-up "nose" technique.** The question is **whether there is a sweet healthy smell, a neutral or absence of smell, or a serious "rotten egg" smell,** indicating an aerobic soil condition, which typically suggests serious problems, especially the blockage of downward water movement.

(3) Next is an examination along the length of the profile for **possible visual symptoms of soil layering or black layer.**

(4) An **examination for an objectionable depth of thatch and/or mat** also is accomplished. In the case of mat, use a knife or similar device to scrape along the top of the profile. This approach will more readily reveal any potential mat that may be present. A thatch accumulation in excess of 0.5 inch (13 mm) and a mat in excess of 0.3 inch (8.5 mm) indicate a proneness to problems.

(5) Next, gently shake the soil profile to allow the soil or root zone mix that is not held together by roots to fall from the lower profile. During this phase an examination is made for the presence of roots. **Typically there is a natural breaking point where a minimum amount of soil/root zone can be shaken loose, which represents the effective rooting depth wherein a majority of the roots are located.** This examination phase also will reveal the relative health of the roots—that is, whether they are white-healthy, medium-brown, or brown to black and non-functioning.

(6) Then **vertically break open the 4-inch diameter rooted soil plug into halves,** and again immediately conduct a "nose" smell assessment. Also, observe the relative health of the root system in terms of a white versus medium-brown versus brown to black. This phase also will allow **examination of the rhizomes** in terms of their relative health as indicated by their thickness and the potential presence of disease lesions or injury from feeding by insects or nematodes.

(7) Throughout the procedure **be alert for signs of pest problems** indicated by the presence of mycelia, fruiting bodies, larvae, and/or adult insects.

(8) Finally, while conducting this assessment it is important to conduct a detailed assessment of the aboveground turf canopy in terms of relative shoot density, leaf color, and presence of lesions or shoot injury to the leaves, crown, and/or stolons.

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Research Summary

Shade Effects on Rooting

The stress problems associated with shaded turfs are readily recognized in terms of thinning of the turf, turf injury from increased disease activity, and more erect elongated narrow leaves. The effects on below-ground root growth are not as readily evident.

This author recently conducted detailed root profile assessments on 108 putting greens within close proximity of one another. As may be expected, substantial variations in rooting depth and root health were observed. Assessments were then made as to the probable causes of the reduced root depth and health. **In 10% of the putting greens with shallow rooting of less than 2 inches (50 mm), the problem was associated with morning shade having a duration of at least three to four hours. Typically these shaded greens had major rooting depth reductions in the order of 50 to 60%.** It was very striking and an obvious cause-and-response situation.

The approach to solving this problem is to raise the cutting height. This allows increased capture of the limited available light, which thereby supplies the carbohydrates needed for root growth. Improved shoot density also may be observed. In order to sustain putting green speeds comparable to the other non-shaded greens which are being mowed at a closer cutting height, a strategy of appropriate rolling can be utilized to provide the uniformity of ball roll distance across all greens of an 18-hole golf course. **James B Beard, International Sports Turf Institute.**

Ask Dr. Beard

Q *In your scientific papers concerning the benefits of turfgrasses, you do not discuss the release of oxygen from grasses during photosynthesis that supports human respiration. Why?*

A It is correct that green, growing turfgrasses have a modest release of oxygen through their stoma that might be available for use in human breathing-respiration activity. Many scientists have promoted this oxygen release as a major benefit of turfgrasses. My assessment has led to a different conclusion. **One must remember that more than 20% of the atmosphere is composed of oxygen.** Thus, there is a question as to just how relevant this turfgrass oxygen release is in terms of "real world" human physiological functions. It is most probably minimal, and thus I have chosen not to list it in my publications and lectures as a benefit of turfgrasses.

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